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Construction Engineering Research Laboratory

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Role of Inspection and Condition Assessment in U.S. Army Corps of Engineers Civil Works Infrastructure Management

Current Practices and Opportunities for the Future

Donald R. Uzarski, David T. McKay, and Stuart D. Foltz

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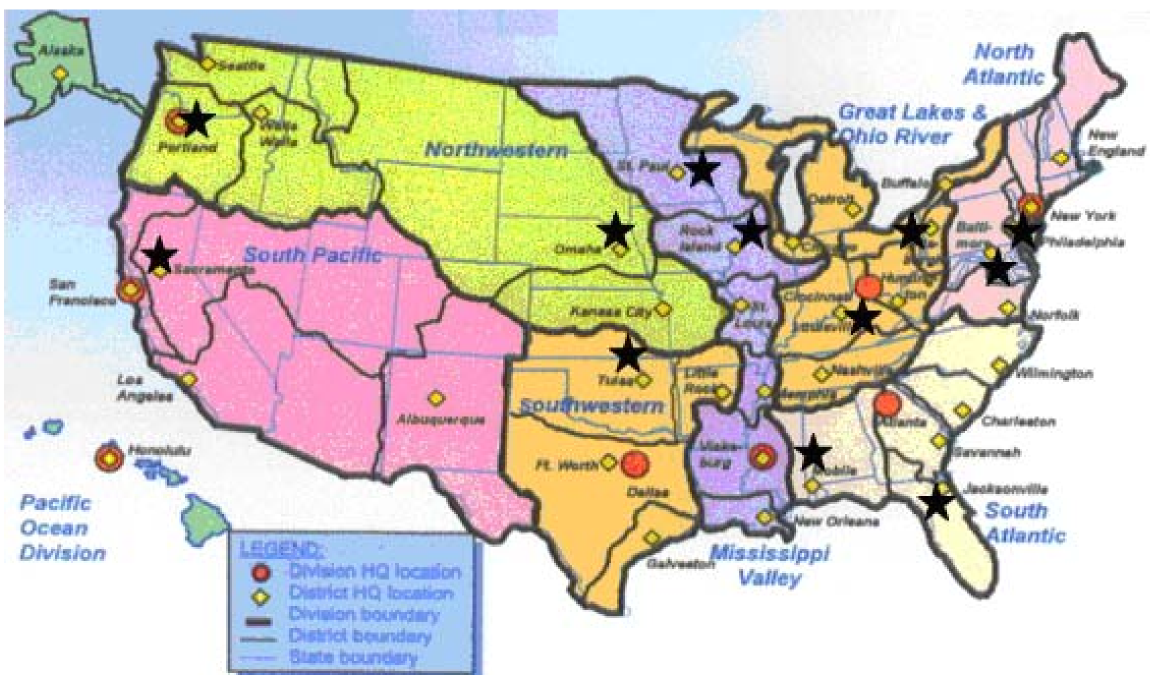

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Abstract: The U.S. Army Corps of Engineers (USACE), Directorate of Civil Works is in the early stages of implementing infrastructure asset management principles to better manage its civil works infrastructure. This effort is being done, in part, in response to Executive Order 13327, which mandates a pragmatic and consistent approach to Federal agency management of real property.

An understanding of how current inspection and condition assessment efforts support infrastructure asset management is needed if USACE is to move forward. The U.S. Army Research and Development Center, Construction Engineering Research Laboratory was tasked with surveying a number of USACE District and Division personnel about their inspection and condition assessment practices and how that supports decisions related to infrastructure asset management.

This report: (1) describes the demographics of the survey participants and explains the different approaches to condition assessment in use within USACE. (All rely on a deficiency-based approach, i.e., deviations from standards or from known benchmarks, to inspection.); (2) describes how inspection and condition information is used in developing work packages, budgeting, and prioritizing work, and also how inspection and condition information is reported for management; (3) provides recommendations for future opportunities that, if developed and adopted, would strengthen the process.

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Preface

This study was conducted for the Operations Division of Headquarters, U.S. Army Corps of Engineers under Project F832CC, “REMR Consumer Reports.” The technical monitor was Jose Sanchez, CEERD-HF-HE.

The work was performed by the Engineering Processes Branch (CF-N) of the Facilities Division (CF), U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL).

At the time of publication, Donald K. Hicks was Chief, CF-N; L. Michael Golish was Chief, CF; and Martin J. Savoie was the Technical Director for the Installations business area. The Deputy Director of ERDC-CERL was Dr. Kirankumar V. Topudurti and the Director was Dr. Ilker R. Adiguzel. The Commander and Executive Director of ERDC was COL Gary E. Johnston and the Director was Dr. James R. Houston.

1 Introduction

Background

Executive Order (EO) 13327, "Federal Real Property Asset Management" (EO 2004) mandates a pragmatic and consistent approach to Federal agency management of real property. The order created the Federal Real Property Council (FRPC) to provide guidance to agencies for improved agency accountability and performance through the application of defined asset management business procedures. The guidance includes principles and strategic objectives, an asset management plan template with required components, and a framework for defining 23 mandatory property inventory data elements and performance measures (FRPC 2004). Those inventory data elements include real property type, usage, size, and a condition index (repair needs cost)/(plant replacement value). The performance measures consist of: (1) utilization, (2) condition index, (3) mission dependency, and (4) annual operating and maintenance costs. These data are to be collected at the "constructed asset" level.*

Real property (facility or infrastructure) asset management means somewhat different things to different people, but can generally be construed to encompass a variety of required decisions and supporting activities related to maintenance, repair, rehabilitation, and demolition that occur during the life of the real property. (Note: For the remainder of this report the more common term "infrastructure" will be used instead of "real property.") These decisions are generally categorized as strategic (network level) or tactical (project level) (Uzarski and Lavrich 1995). Strategic decisions address "what, where, when, and budgeting" questions. Tactical decisions address "how best" questions. Both types require certain information be provided to the decisionmaker. This information includes, but is not limited to: inventory, inspection results, condition assessments, functional assessments, asset utilization, asset criticality (importance to mission fulfillment), work needs identification, available funds (budget), execution constraints, and consequence analysis. Not all of this information is required for every decision and the "granularity" of the information used can vary for a given decision. Tactical decisions generally require more detailed information than strategic ones. Some of this information is

* On the military side of USACE, "constructed asset" is well defined; however, it is a term lacking complete definition in the context of Civil Works.

extracted from data (e.g., inventory and utilization), some is based on external factors (e.g., budgets and constraints), and some is based on analysis and modeling (e.g., assessments and consequences). However, regardless of the decision at any given time, the universal goal of infrastructure asset management is to maximize infrastructure performance, consistent with need, at the lowest possible life-cycle cost. Both strategic and tactical decisions must be made at appropriate times during the lifecycle for that to happen.

Asset management has been practiced for as long as infrastructure has existed. Traditionally, the practice has been more “art” than “science.” The more successful managers are well versed in their infrastructure, experienced, adept in communicating needs, understand the “system” within which they work, and have a flair for the topic. They are part engineer, manager, magician, politician, and fortune teller.

Over the past quarter century or so a structured approach to infrastructure asset management has evolved. This evolution from “art” to “science” is due, in part; to recognition by many that the “old school” business practices are not up to the challenge. Certain academia, government, and professional organizations (public and private) have recognized that infrastructure asset management is an emerging science. For example, the American Society of Civil Engineers (ASCE) is fostering infrastructure asset management science. Their Infrastructure Systems Committee (ASCE 2008) within the Transportation Institute is charged with, in part, “... promot[ing] the understanding and advancement of infrastructure management sciences such as condition assessment, performance modeling, decisionmaking and financing strategies and innovative technology and practices.” As another example, the U.S. Army Engineering Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) has been a leader in the development and advancement of infrastructure asset management technology during this past quarter century. ERDC-CERL has developed computer-based infrastructure asset management systems (called either Engineered Managements Systems or Sustainment Management Systems) for pavements (PAVER) (CERL 2008a), railroad track (RAILER) (CERL 2008b), built-up roofing (ROOFER) (CERL 2008c), and buildings (BUILDER) (CERL 2008d) as well as inspection and condition rating methodologies for Civil Works structures (Foltz and McKay 2008). While these systems have been implemented to varying degrees of success at many locations both within the Department of Defense (DOD) and the civilian sector, these systems are

basically technology transfer mediums for infrastructure asset management technologies. These technologies include, in part: Standardized inventory processes, new or revised inspection approaches, condition assessment metrics, condition prediction models, maintenance and repair planning processes, prioritization models, and consequence models. The systems themselves are capable of producing strategic and tactical analyses needed to support infrastructure asset management decisionmaking. Some civilian sector (both public and private) agencies and companies, respectively, have also developed systematic approaches to infrastructure condition assessment (Foltz and McKay 2008). Some have adopted ERDC-CERL technology or developed their own, bundled it into a computer-based system, and applied it to a variety of infrastructure.

Within the U.S. Army Corps of Engineers (USACE), the management of civil works (CW) infrastructure assets is largely decentralized. This infrastructure resides within eight Divisions generally defined by watershed boundaries. The Divisions are further divided into 36 Districts where the day-to-day activities regarding infrastructure take place (USACE 2008). The actual CW infrastructure (e.g., dams, levees, etc.) is physically located by "project." Most projects have District personnel assigned to them to perform certain day-to-day activities. These activities generally encompass a variety of infrastructure operations and maintenance (O&M) tasks. Also, each project falls under the purview of a specific business area that reflects the primary mission or purpose of the project. These specific infrastructure related business areas are: Navigation, Flood Damage Reduction (FDR), Hydropower, Recreation, and Water Supply.

In partial response to EO 13327, the USACE Directorate of Civil Works is in the early stages of implementing infrastructure asset management principles throughout the directorate, which includes the Divisions and Districts. An asset management plan has been promulgated (USACE 2006). Expected benefits include the establishment of standards and criteria that will facilitate O&M budgeting, scheduling, life-cycle performance optimization, and risk reduction.

As can be deduced from the above, condition assessment is an essential element to infrastructure asset management. Thus, for USACE to comply with EO 13327, condition assessment must play a pivotal role in any approach (or approaches) taken to manage CW infrastructure assets. District, Division, and headquarters-level decisionmakers must have an understanding of the current and expected condition of their CW

infrastructure assets to make sound strategic and tactical decisions regarding that infrastructure. Operating largely independently, but following various policy regulations and instructions promulgated from headquarters, Districts currently conduct periodic and event-driven inspections to ascertain condition from which required corrective work activities are identified, prioritized, budgeted, and finally executed. However, it is also established that the Districts have developed different and varied approaches to determining condition and using that condition information in the decisionmaking process. These varied approaches may or may not be conducive to USACE-wide infrastructure asset management.

Objective

The objective of this study was to determine if the various condition assessment approaches used by Districts are conducive to USACE-wide CW infrastructure asset management or if different (or additional) broadly applicable methods of assessing condition are needed. This determination includes what condition-related data are collected, how the data are translated into useful and meaningful condition measures and information (if at all), how that information is used in the business processes (strategic and tactical decisionmaking) for managing CW infrastructure, and how the information is shared at various management hierarchical levels.

Approach

The approach taken in this research was to telephone knowledgeable District and Division personnel to discuss their perspectives on how CW infrastructure condition is assessed, including the inspection process, and how that information is used and shared specifically with respect to developing work packages, budgeting, prioritization, overall District and Division business decisionmaking, and reporting (information flow). These are all key CW asset management activities. The survey was initiated using a contact list of personnel known by the authors. Most were Dam Safety Managers, but others were contacted, including people working in the Navigation business area. Additional people were interviewed based on recommendations of previous interviewees. Condition assessment of hydropower equipment was beyond the scope of this survey, which was intended to cover a representative sample of perspectives on infrastructure condition assessment within the USACE.

Report organization

This report begins with information, statistics, and a summary of survey question responses, followed by a description of current CW inspection and condition assessment approaches. The usage of condition information in executing various CW infrastructure asset management tasks is then presented. Finally, conclusions are made about how current practices mesh with certain modern asset management principles. Several recommendations are offered that, if adopted, would advance the implementation of infrastructure asset management principles.

From time to time in this report, examples of District practices are cited. Generally, these examples are for illustrative purposes only and not intended to imply that they are unique to those Districts. However, where District practices are unique and cited in this report, those Districts are so noted.

2 Information Collection

The information collection survey process began with a Memorandum for Distribution dated 2 November 2007, from the Acting Chief, Operations, Directorate of Civil Works, to an initial list of potential contacts. The memorandum served as an introduction and explained the goal of the survey. Appendix A includes this memorandum. The initial list of contacts consisted primarily of Dam Safety Officers. The intent was for these individuals to offer additional referrals so that a complete picture would emerge. A survey questionnaire was prepared to guide the survey process. Appendix B includes this two-part questionnaire. The surveys were conducted between November 2007 and February 2008. A call log was maintained and is presented in Appendix C.

Survey respondent statistics

Each person on the initial list was called, but the response rate was not 100 percent. Through referrals, ultimately 30 people were actually surveyed out of a total of 46 called. This resulted in a response rate of 65 percent. Seven of the eight Divisions (all except Pacific Ocean Division) were represented for 87 percent coverage. One or more persons within 12 Districts were surveyed providing for 33 percent District coverage. Tables 1 and 2, respectively, list the Divisions and Districts and number of people surveyed. Note that the South Pacific Division office did not have a direct respondent, but the Sacramento District, which is located within the South Pacific Division, was represented. Figure 1 shows the locations.

Table 1. Division participation in condition assessment survey.

USACE Division	Number of People Surveyed
South Atlantic	1
Southwestern	1
Great Lakes and Ohio River	1
North Atlantic	1
Northwestern	1
Mississippi Valley	1

Table 2. District participation in condition assessment survey.

USACE Districts	Number of People Surveyed
Jacksonville	2
Rock Island	6
Pittsburgh	2
St. Paul	2
Philadelphia	1
Omaha	1
Mobile	1
Louisville	2
Portland	2
Tulsa	1
Sacramento	1
Baltimore	3

Source: U.S. Army Corps of Engineers Asset Management Plan, 4 July 2006

Figure 1. Division and District survey locations (marked with a star).

All but two of the survey respondents were engineers. Table 3 summarizes the various Divisions in which the respondents work, and Table 4 summarizes the variety of positions in which they are employed.

Table 3. Survey respondent Divisions.

Division	Number of People Surveyed
Operations	10
Engineering	15
Business Resources	1
Business Technical	3
Program Management	1

Table 4. Survey respondent positions.

Position	Number of People Surveyed
Dam Safety Program Manager	12
Operations Chief/Manager/Assistant	6
Project Manager	2
Project Engineer	1
Project Manager for Asset Management	1
Program Analyst	1
Navigation Business Manager	1
Engineering Chief	1
Technical Specialist/Leader	2
Inspection Team Leader	1
Flood Protection and Natural Resources Chief	1
Risk and Reliability Leader	1

Inasmuch as the focus of this survey was to interview personnel who create or use condition data, all of the respondents had responsibility and/or expertise regarding the variety of dams, levees, and/or key features such as dam gates, locks, etc. in their respective geographical areas.

3 Survey Responses Regarding Condition Assessment Within USACE

Many engineers, both inside and outside of USACE, consider condition assessment and inspection to be one-and-the-same, and the terms are often used interchangeably. However, if the condition assessment process is divided into its logical steps, the process begins with data collection (inspection) and concludes with a data analysis regarding condition (assessment). This chapter first addresses several inspection issues and then discusses assessment, as currently being practiced within USACE primarily for FDR and navigation CW infrastructure.

Inspection type and frequency

The survey respondents stated that required inspections, as per Engineer Regulation (ER) 1110-2-100 (ER 1995), are being accomplished. These include both formal periodic inspections and informal inspections. All respondents who were familiar with the inspection program in their Division or District stated that, as a minimum, 5-year formal inspections are being conducted by multi-disciplined District teams. In many instances Division personnel participate. Five-year maximum inspection cycles are required "... if warranted by the results of previous inspections" for dams, appurtenant structures, and navigation structures (ER 1995). Most respondents also stated that formal intermediate inspections on varying frequencies are also being accomplished as required (ER 1995), by either District or local (project) personnel. Generally, this is a smaller team and membership is often specialized based on the specific needs and history of the project being inspected. Some of these inspections are calendar-based (e.g., annual inspection), whereas others are event-based (e.g., pool elevation, earthquake, etc.) Additionally, local operations personnel perform informal inspections (ER 1995) of their locks, dams, levees, etc. looking for problems. Sometimes these informal inspections may discover something (e.g., unusual or unexpected crack) that may trigger an intermediate or "special" inspection by a District engineer who will further analyze the "problem." Also, inspection is an element of local preventive maintenance (PM) programs.

Some Districts have tailored inspection programs to address local needs. For example, the Jacksonville District has developed a surveillance plan

for embankment dams. Inspection frequency depends on lake elevation. As lake levels rise, inspection frequencies vary increasing from 90 days to daily. These inspections are conducted by local operations personnel, but the District personnel help, as needed.

There are instances when the inspection interval for certain features is longer than 5 years. St. Paul and Tulsa Districts both responded that dewatering is required to thoroughly inspect gates and other underwater features. These dewatering intervals varied from 10 to 15 years. Dewatering is no trivial matter. It is expensive and affects pool beneficiaries.

On the other hand, sometimes the project is inspected at less than a 5-year interval. For example, a particular (but unnamed in the survey) project in the Portland District is said to be at increased risk. Thus, it is being inspected on a 3-year cycle.

Visual inspections

ER 1110-2-100 states that a formal technical report of inspection shall be prepared and "... based on a detailed, systematic technical inspection and evaluation of each structure and its individual components regarding its safety, stability, and operational adequacy" (ER 1995). The primary method that the teams use for accomplishing these periodic inspections is visual. Prior to actually inspecting, the inspection team reviews previous inspection reports and talks with project personnel to gain insight to project problems and issues. Each team member, being an expert in a specific area (e.g., geotechnical, mechanical, electrical, etc.), then proceeds to visually inspect. With a trained and critical eye, each team member walks through and about the project looking for deficiencies that need to be corrected. Sometimes divers are employed to inspect underwater features.

Deficiencies, as discussed with the respondents, are deviations from design and/or construction standards to which the structure or component was built, deviations from known benchmarks established partly on experience, or new standards. There is an inherent implication that the standards (in effect at the time of design and/or construction) meet safety, stability, and operational requirements. A certain amount of judgment is required to determine if a deficiency exists. Simply having a deviation from a "pristine" state does not necessarily constitute a deficiency. The inspector, being an expert, will make the call as to whether any deviation is significant enough to be called a deficiency and thus warrant corrective

action. Some dam safety professionals do not share this definition. For example, Bowles (2006) believes that the term “deficiency” should be reserved for the situation in which an adequate justification to proceed with a risk reduction has been demonstrated and that “dam safety issue” should be used in all other cases. While this may have merit from a dam safety perspective, the term “deficiency” is used in a broader infrastructure asset management environment to mean a deviation from what is acceptable and that was the intended usage in the discussions with the survey respondents.

To aid inspectors, inspection checklists are widely used. These checklists generally provide the list of specific project features that are to be inspected and may also suggest to the inspector the nature of the deficiencies that may be present. ER 1110-2-101 (ER 1996a) offers a listing of distress (deficiency) signals that form a basis for the checklists. For example, a project in the Portland District includes concrete condition and signs of movement as suggested items to look for in a spillway service gallery. Another example is for embankments at a project in the Philadelphia District. Inspection items include: surface cracks, abutment and embankment junctions, vertical and horizontal alignment, unusual movement or cracking at or beyond toe, unusual seepage through embankment or downstream seepage, and others. However, even though checklists and ER 1110-2-101 suggest inspection items such as “concrete condition” and “unusual movement or cracking,” the judgment and expertise of the inspector are required to evaluate what constitutes a deficiency and what does not (e.g., concrete cracking and spalling – how much, how bad?) Perhaps the greatest value of the checklists is that they help ensure that something (e.g., a feature or problem) is not overlooked. This adds a semblance of structure to an otherwise inherently ad hoc process. The checklists may also be used as a template to record deficiency information. Checklists also establish a language for purposes of sharing and comparing condition information.

Photographs and measurements (e.g., crack width and length) often play a significant role in the inspection process. Not only do they provide a record of the degradation state at the time of inspection, they also provide a basis for evaluating change from one inspection to the next.

Monitoring data

Without exception, the respondents stated that monitoring data are an essential part of the inspection process. Examples of this data include: piezometer, uplift pressure cell, sump inflow, inclinometer, tiltmeter, and crack meter readings. The norm is to have local project personnel collect the data (readings) and forward them to the parent District for analysis. Reading frequency varied from one site to the next. In a few locations data are read and transmitted automatically to the District office.

These data serve many purposes. One, of course, is to provide a snapshot in time of the various readings. This snapshot is compared to normal readings. The data may be plotted or otherwise analyzed for trend patterns. Anomalies in the readings (those that exceed threshold levels) also alert engineers to potential problems. Trend patterns may also be indicative of potential problems. Depending on the results of the data analysis and a review by a specialist, no additional action may be necessary, more frequent monitoring may be required, a visual inspection may be conducted to investigate the anomaly, or the item may be noted for resolution during the next inspection (5-year or interim). The goal is to discover and rectify problems early to ensure safety and stability.

Another form of monitoring data is that collected from monument (alignment) surveys. The purpose of these surveys is to determine if any movement in the structure has occurred, and if so, how much. These surveys are often conducted as part of the periodic inspections, but events such as earthquakes may trigger one. If movement is detected, a more in-depth inspection and engineering analysis may be called for to determine cause and possible solutions, if warranted.

Other inspection methods

Other methods, other than visual or monitoring, are used to supplement the 5-year inspections and sometimes the intermediates. These include the use of ultrasonic testing of welds, ground penetrating radar (GPR) to look for voids, equipment performance testing, material (e.g., concrete) sampling for further laboratory testing, and tension meters for cable testing. Such methods may also be used on an "as needed" basis should issues arise at any time.

Levels of inspection

In general for a project as a whole, the 5-year periodic inspections are the most comprehensive but typically not intensive. Intermediate inspections are usually less comprehensive and the informal inspections are even less. Intermediate inspections can also be quite comprehensive, but limited to specific features (e.g., embankments). Some respondents referred to the intermediate inspections as a faster version of the 5-year inspection. The informal inspections are the least thorough (from an engineering perspective) because local personnel are generally not engineers and thus lack the necessary engineering expertise required for making the judgment calls inherent to the inspection process. This is not to say that local personnel are not highly skilled. They form the “first line of defense” in spotting and communicating deviations from the norm. Their preventive maintenance efforts are critical to finding and rectifying small problems before they result in service failures and/or a major deficiency. One respondent felt that the informal inspections were the most thorough because maintenance personnel were more focused and familiar with the equipment and issues. Another saw no difference in the inspection results between the 5-year and intermediate inspections even though more specialists were involved in the 5-year inspections.

As discussed earlier, in some instances dewatering is needed to thoroughly inspect certain features, and the dewatering process is on a much longer frequency than 5 years. When dewatering is done, the inspections are very thorough and detailed, more so than can be accomplished by divers. It may even encompass some nondestructive testing such as ultrasonic testing of certain welds. When the opportunity to thoroughly inspect arises, it should be taken because several years may pass before the opportunity arises again.

Any deficiency found during the 5-year or intermediate inspection may require a further in-depth inspection and analysis. These may include using supplemental methods as described above or a more intense visual inspection, if required. The goal is to fully understand the extent and cause of the deficiency so that a proper recommendation can be made.

Adequacy/quality of inspection information

The majority of the respondents believe that the collected inspection information (all types, collectively) is adequate for their needs. However, not

all agreed. One respondent stated that sometimes the young engineers were not yet well versed in their respective fields and perhaps lacked the requisite judgment skills necessary for a thorough inspection. Others stated that funding limitations have adversely affected both the size of the inspection team and the time spent inspecting at a project. Also, one respondent stated that failed monitoring instruments were not always being replaced due to budget limitations. Some felt that more detail is needed in certain cases. Interestingly, one respondent was concerned that inspectors may become "too familiar" with projects (condition and culture) to the point that they may miss deficiencies; thus a fresh perspective is necessary from time to time to ensure a quality inspection. Thus, all of these issues, in part or collectively, may affect the quality of the inspection; however, the authors of this report have no basis upon which to verify if quality has indeed suffered. One respondent felt that inspections of certain features were not being conducted often enough. More than one respondent felt that inspections do not adequately address dam safety risk; that is, inspection frequency and level of detail should be risk based. Also, some believed that the more critical the feature or component is, the more detailed should be the inspection.

None of the respondents felt that they had too much information.

Condition assessment

Condition assessment can involve different forms of analysis such as subjective opinion, mathematical models, or variations thereof. "Condition" is a physical "state" that must be described through the use of one or more meaningful metrics. Analysis of inspection data provides a measure against these condition metrics. Condition metrics generally take the form of a rating or a mathematically computed index. A few different approaches are being used within USACE.

Overall project rating

ER 1130-2-530 (ER 1996b) describes a five-level condition rating metric that is applied to projects, as a whole, upon the conclusion of a periodic inspection. Table 5 lists these ratings. This condition rating approach is highly subjective in that the source data (inspection) is, in itself, subjective (see discussion of inspection above) and the rating assignment requires judgment.

Table 5. Overall project condition rating scale.

Rating	Rating Criteria
C1 - Excellent	No major deficiencies. None or few minor new deficiencies. All old deficiencies noted in the last inspection have been corrected.
C2 - Very Good	No major deficiencies. Several new minor deficiencies. Most old deficiencies noted in the last inspection have been corrected.
C3 - Good	Few or no new major deficiencies. Numerous new minor deficiencies and/or several old minor deficiencies noted in the last inspection have not been corrected. Annual maintenance performed, but additional effort is needed.
C4 - Fair	Major deficiencies that, if not corrected immediately, may lead to or cause deterioration of the project such that it is incapable of providing the maximum flood protection. Little or no evidence of minimum maintenance performed. A greater effort is required to reduce deficiencies.
C-5 Poor	Major deficiencies such that the structural integrity or the flood control project will probably not withstand a major flood event. Little or no evidence of maintenance performed.

Component ratings

Some of the respondents take the notion of the overall project condition rating a bit farther and apply the concept to pivotal components within a project. The Great Lakes and Ohio River Division (LRD) has developed such a procedure as part of their effort to improve CW infrastructure asset management processes. Table 6 describes the condition assessment standards that have been developed. In this approach, a multi-disciplined Facility Condition Assessment Team (FCAT) assigns a condition classification as described in Table 6 to the various components in a project based on the periodic inspection results and field verification. After the initial baseline assessments are completed, they are planned to occur along with the 5-year periodic inspections and at the 3-year mark.

Table 6. Condition assessment standards (LRD).

Asset Management – Condition Assessment Standards	
Condition Classification	Definitions
A Adequate	There is a high level of confidence that the feature will perform well under the designed operating conditions. This confidence level is supported by data, studies, or observed project characteristics which are judged to meet current engineering or industry standards. There is a limited probability that the verified degraded conditions will cause an inefficient operation, or degradation or loss of service.
B Probably Adequate	There is a low level of confidence that the feature will perform well under designed operating conditions, and may not specifically meet engineering or industry standards. The feature may require additional investigation or studies to confirm adequacy. There is a low probability that the verified degraded conditions will result in inefficient operation, or degradation or loss of service.
C Probably Inadequate	There is a low level of confidence that the feature will not perform well under designed operating conditions, and may not specifically meet engineering or industry standards. The feature may require additional investigation or studies to confirm adequacy. The feature does not meet current engineering or industry standards. There is a moderate probability that the verified degraded conditions will result in inefficient operation, or degradation or loss of service.
D Inadequate	There is a high level of confidence that the feature will not perform well under designed operating conditions. Physical signs of distress and deterioration are present. Analysis indicates that factors of safety are near limit state. The feature deficiencies are serious enough that the feature no longer performs at a satisfactory level of performance or service. There is a high probability that the verified degraded conditions will result in inefficient operation, or degradation or loss of service.
F Failed	The feature has FAILED . Historically the feature regularly experiences scheduled or unscheduled closures or loss of service for repairs.

Narrative

As part of the periodic inspection process, a narrative is written that explains the deficiency and offers a recommendation for correction along with a priority (ER 1995). Sometimes, undefined condition rating terms such as “good,” “excellent,” or something else may be used in the narrative. A cost estimate for the correction is typically added later. The strength of the narrative, which often includes a sense of urgency for repair (e.g., repair within the next 12 months); the criticality of the feature to safety, failure risk, and/or operations; the consequences if repairs are not made (sometimes); and a cost is viewed by some to be a de facto condition assessment. There is a common presumption that higher urgency, greater risk, or higher criticality of the feature and/or higher repair cost equate to a “worse” condition.

Experience "rating"

There were a few respondents who prided themselves in their intimate knowledge of one or more projects and thus, they "knew" what the condition was, even though they could not really define it. This knowledge stems from judgment and experience. (One respondent used the term "gut instinct.") Certainly they were aware of problems and where management attention needed to be focused. This is, indeed, another form of condition assessment. Even though condition may not be defined, per se, there is meaning to the "rater." This practice is the ultimate form of subjective rating.

REMR Condition Indexes (CIs)

Most of the respondents were familiar with or at least had heard of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) CI approach to condition assessment. The REMR CI approach uses a 0 – 100 condition scale with 100 being the anchor to the scale and representing a "free from observable distress" condition state. These are feature-specific CIs. A full description can be found in Foltz and McKay (2008). This condition assessment approach uses mathematical models to calculate a CI, based on a highly structured, mostly objective rather than subjective inspection process. A few have used the REMR CI process in the past. None are using the process at present. Foltz and McKay (2008) report from a previous survey the perceived pros and cons of REMR CIs and the reasons why they are not in current use.

Pavement Condition Index (PCI)

Both the Rock Island and Tulsa Districts have in the past used PAVER (CERL 2008a), which incorporates the mathematically computed PCI as the condition assessment metric. The PCI is obtained by following a structured condition survey process. Like the REMR CIs, the PCI uses a 0 – 100 condition scale with 100 being the anchor to the scale and representing a "free from observable distress" condition state. Funding constraints have led to a reduction in PAVER usage in the Tulsa District.

Screening for Portfolio Risk Assessment (SPRA) for dams

Several of the respondents referred to a new initiative called the Screening for Portfolio Risk Assessment (SPRA). Intended for dam safety, SPRA is a holistic, condition-related, risk assessment process that results in an assignment of a Dam Safety Action Classes (DSACs) I through V (EC 2007).

To use SPRA, a multidisciplinary cadre of experts meets and reviews historic and current project information, including periodic inspection reports, and evaluates common failure modes, their probabilities, and consequences. While the information the team reviews is on a detailed level, the screening framework and analysis is a much higher granularity. This is an analytical process with certain subjective elements. The process includes no inspection by the expert cadre. There is no standardized process for identifying distresses or evaluating condition. Repair requirements are determined by the cadre primarily based on the District's existing "job jar" since the cadre usually has no first-hand knowledge of the project. (Job jar is discussed later in this report.) The analytical risk analysis framework has been developed to assure uniformity in comparisons of projects and their dam safety deficiencies based on the probability of failure, the consequences (life loss or economic), and estimated repair costs. With guidance, the projects are then subjectively placed in a dam safety action classification. Table 7 shows the DSACs (extracted from EC 2007). The classification is intended to be dynamic. Classification can change as project characteristics change or the loading, probability of failure, or consequences change (either actual change or situational understanding change). Thus, once the initial screenings are completed, future screenings are case-by-case. Approximately 30 percent of the USACE portfolio of dams was assessed in Fiscal Year (FY) 2005-07. The remaining dam inspections are to be completed in FY08-09.

Table 7. USACE Dam Safety Action Classification Table.

Table 1 USACE Dam Safety Action Classification Table*

Dam Safety Action Class	Characteristics of this class	Actions for dams in this class
I **URGENT AND COMPELLING** (Unsafe)	**CRITICALLY NEAR FAILURE** Progression toward failure is confirmed to be taking place under normal operations. Almost certain to fail under normal operations from immediately to within a few years without intervention. **OR EXTREMELY HIGH RISK** Combination of life or economic consequences with probability of failure is extremely high.	Take immediate action to avoid failure. Validate classification through an external peer review. Implement interim risk reduction measures, including operational restrictions, and ensure that emergency action plan is current and functionally tested for initiating event. Conduct heightened monitoring and evaluation. Expedite investigations to support justification for remediation using all resources and funding necessary. Initiate intensive management and situation reports.
II **URGENT** (Unsafe or Potentiall Unsafe)	**FAILURE INITIATION FORESEEN** For confirmed (unsafe) and unconfirmed (potentially unsafe) dam safety issues, failure could begin during normal operations or be initiated as the consequence of an event. The likelihood of failure from one of these occurrences, prior to remediation, is too high to assure public safety. **OR VERY HIGH RISK** The combination of life or economic consequences with probability of failure is very high.	Implement interim risk reduction measures, including operational restrictions as justified, and ensure that emergency action plan is current, and functionally tested for initiating event. Conduct heightened monitoring and evaluation. Expedite confirmation of classification. Give very high priority for investigations to support justification for remediation.
III **HIGH PRIORITY** (Conditionally Unsafe)	**SIGNIFICANTLY INADEQUATE** **OR MODERATE TO HIGH RISK** For confirmed and unconfirmed dam safety issues, the combination of life or economic consequences with probability of failure is moderate to high.	Implement interim risk reduction measures, including operational restrictions as justified, and ensure that emergency action plan is current and functionally tested for initiating event. Conduct heightened monitoring and evaluation. Prioritize for investigations to support justification for remediation considering consequences and other factors.
IV **PRIORITY** (Marginally Safe)	**INADEQUATE WITH LOW RISK** For confirmed and unconfirmed dam safety issues, the combination of life or economic consequences with probability of failure is low and may not meet all essential USACE guidelines.	Conduct elevated monitoring and evaluation. Give normal priority to investigations to validate classification, but no plan for risk reduction measures at this time.
V **NORMAL** (Safe)	**ADEQUATELY SAFE** Dam is considered safe, meeting all essential USACE guidelines with no unconfirmed dam safety issues. **AND RESIDUAL RISK IS CONSIDERED TOLERABLE.**	Continue routine dam safety activities, normal operation, and maintenance.

* At any time for specific events a dam, from any action class, can become an emergency requiring activation of the emergency plan

Potential Failure Modes Analysis (PFMA)

The PFMA follows the SPRA and is applied only to Dam Safety Action Classification (DSAC) I, II, and III dams (see Table 7). In this process a multidisciplinary team reviews historic and current information, including periodic inspection reports, and brainstorms potential failure modes for a given project. A PFMA category (I through IV) is assigned that ranges from (I) those failure modes of greatest significance and (IV) having potential failure modes ruled out. This feeds the Initial Risk Reduction Measures process for determining measures to be taken to reduce risk. The focus of this analysis is major rehabilitation.

Major rehabilitation evaluations

Various probabilistic methods have been developed to evaluate both the life safety and economic risk aspects of civil works infrastructure including navigation locks and dams. These methods include the use of probabilistic analytical models, historical data, and expert opinion when modeling is not a viable option and historical failure data are not available or comprehensive enough for risk assessment purposes. In general, historical failure data of civil works infrastructure are not sufficient enough to use for detailed risk assessment studies, such as major rehabilitation evaluations. All the methods continue to be improved with better modeling techniques and improved tracking of historical failures. Accurately assessing the current condition of major infrastructure, such as miter gates on navigation locks, plays a critical role in ensuring the reliability analysis is calibrated with actual field conditions.

Perceived usefulness of condition metrics

Respondents were asked if condition metrics were useful or important. Eighty percent believe that they are, 10 percent believe that they are not, and 10 percent are not sure.

Of those who support the idea, most had qualifiers to their response. All felt that by having an appropriate metric (undefined in this survey) benefits would accrue. Nearly all felt that the condition assessment process would be more objective and consistent than it is now. Some added that a benefit would be a standardized inspection with less bias. Some believed that the playing field would be leveled regarding funds allocation. Some also believed that such metrics would help justify a bigger funding pie overall and add credibility to higher authority, including the U.S. Con-

gress. One respondent believed that a condition metric would add significance when communicating needs and explaining why to nontechnical people. Still another respondent felt that a condition metric would enhance the SPRA process discussed above. Finally, one respondent felt that having metrics would make his job of budget preparation and justification easier.

One of the qualifiers stated by a few of the respondents was that such a metric must incorporate risk (or reliability) to be useful. Others said that if metrics such as those displayed in Table 6 are applied “across-the-board” for apples-to-apples comparisons, especially when risk is a factor, different (but equivalent) definitions would be needed for different infrastructure types. This is particularly germane when crossing business lines. Also, some said that a narrative is needed to support the metric because the metric, in itself, does not tell the whole story.

On the negative side, one respondent said that he does not see a value in a “pure number” and it may give a false indication of dam safety. Two of the respondents who are not in favor of condition metrics stated that engineering judgment and experience coupled with analysis is the essential means for assessing condition. One stated that not only are metrics not helpful to him, but that they would likely cause grief if they were unfavorable.

From the “not sure” perspective, one respondent said that metrics are important, but questioned whether they are worth the effort to obtain them and if they would really make any difference concerning funding. Others said that metrics may be useful for certain infrastructure items, but that more than a “number” is needed. Another said that a common metric for the purpose of apples-to-apples comparisons is not always a good idea. Using the same condition metric may result in misapplication and misinterpretation between dissimilar infrastructure and that perhaps different condition metrics should be used for different infrastructure types. One respondent strongly believed that engineering judgment and communication are the keys to success at the local level, but that metrics have their place at higher management levels for securing and allocating funds.

4 Survey Responses Regarding the Role of Condition Assessment in Asset Management

As part of the survey, the respondents were asked about their roles in CW asset management and how condition assessment supported various asset management tasks.

Respondents participation in CW asset management activities

During the course of the survey, each respondent was asked to explain in his/her own words how they participate in the CW asset management process. Table 8 summarizes those responses. Some of the respondents participate (or have participated) in multiple activities and thus the numbers total higher than the number of respondents. Those summarized in Table 8 represent a generalized aggregation of what the respondents do; thus, their specific participation will vary from one District to the next. Also, the participation summary focuses on the activities that the respondents most readily discussed. It is likely that some respondents do touch upon, albeit indirectly or to a minor degree, more activities than they reported, but the intent of the survey question was to obtain generalized background information and not to solicit job description details.

Although respondents all perform certain CW asset management activities, nearly all displayed knowledge of other activities. For example, all were familiar with the periodic inspection program even though only a third was directly involved with it. Likewise, all knew that work packages were prioritized. Some were directly involved in that process; some were not involved but knew how it was done; others were unaware about how it was done. The following reports how respondents used condition information in various CW infrastructure asset management activities.

Developing work packages

Numerous work packages are created each year. Some are a direct outcome of the periodic inspection process. As discussed earlier, work packages result from the recommendations to correct deficiencies. Sometimes the justification includes a recommended timeframe for accomplishment (urgency factor).

Table 8. Respondent participation in CW asset management activities.

CW Asset Management Activity	Number of Respondents
Inspect or Oversee Inspection	10
Prepare or Technical Review Work Packages	2
Prioritize Work Packages	10
Perform Risk Assessments	3
Prepare, Influence, or Recommend Budgets	16
General Oversight or Supervision	8
Work Execution	2

Events often occur that result in the creation of work packages outside of the periodic inspection program. Damage or failure resulting from a natural event (e.g., earthquake) or human error (e.g., impact from a river barge) will trigger some sort of a special inspection from which a work package for repair will likely result.

Historical trends (baseline) and/or experience were cited by some respondents as a means for developing work packages. Examples of work packages developed this way are those for annual operations and maintenance (O&M) and special studies.

Budgeting

All of the respondents who were involved or familiar with the budget process stated that condition information was important inasmuch as a significant portion of the budget is devoted to deficiency correction work packages. Recommendations, especially when accompanied with a recommended timeframe for accomplishment, will affect what gets funded and what does not in a given year.

Budgeting and prioritization are closely linked. Budgeting, in many respects, really means budget allocation or how one spends the budget one receives. Clearly, those work packages with the highest priority should be funded. However, if a particular item is especially large (dollars and/or scope) a separate supplemental funding may be requested.

The planned budget may be disrupted due to unexpected inspection findings or emergencies. If an inspection revealed that work was urgently needed and unacceptable risk was present, a budget “plus up” or reprogramming would be requested. This urgent work could be a surprise

stemming from a deficiency found during a periodic inspection or it could be event-driven stemming from a natural disaster or human error.

Prioritization

Prioritizing work packages for execution is an essential element to infrastructure asset management. This is because needs always exceed resources. All respondents reported that prioritization of work packages was being accomplished; however, a quarter of them did not know how work packages were prioritized. Although prioritizing work is a common activity, the way it was done does vary. Many stated that their Dam Safety Committee played a key role in prioritizing work. The responsibilities of the Dam Safety Committee, including prioritizing dam-safety-related work, are spelled out in ER 1110-2-1156 (ER 1992). One respondent said that all dam safety work packages have the same high priority. Regardless of how the prioritization is done, condition is a critical element in the process. Condition is a major factor in evaluating risk (safety, operations, or both). Maximizing risk reduction is a goal of the work prioritization process. The different basic methods used are summarized below. Within a basic method, though, specifics varied to meet the particular needs or desires of the District. Certainly, the work package prioritization is a dynamic process. The process is such that work packages for baseline operations rise to the top.

Judgment/experience

One-third of the respondents stated that the list of work items is prioritized based on the judgment and experience of the people doing the ranking. Risk is often considered in a subjective way. Reliance is often made on the strength of the work package write-up and recommendations therein, especially when the recommendations provide a timeframe for when the work should be done. Sometimes this recommendation places the work into different funding categories (e.g., dam safety, navigation, hydropower, etc.) within which work packages may or may not be further ranked based on judgment and experience.

Point ranking

Almost 25 percent said that they use a variety of ranking criteria and assign points depending on how the work packages meet the various criteria. The points are totaled, thus providing for a ranking. Those that use this approach stated that condition is a factor, but without a condition metric,

it is considered subjectively within one or more criteria. An example is that developed by Mississippi Valley Division (MVD) for navigation (USACE 2007). Several criteria are used, including: criticality, traffic, navigation benefit, environmental benefit, unfunded duration, construction impact, inland waterways trust funds, safety, and benefits. Each of these contributes a certain number of points (weights) to a total for a given work package. Different criteria contribute unequally to the total. Condition is a major consideration and included in criticality. Criticality points are based on risk of failure within 5 years and consequences if it does fail. For most of the criteria, a team subjectively assigns the points. For others (e.g., traffic) points are set based on magnitude. *

Analytical

The analytical approach is an advanced form of the point ranking approach discussed above. The intent of the analysis is to reduce subjectivity and enhance objectivity. Seventeen percent of the respondents were using or familiar with analytical approaches. Two examples that describe analytical processes from two different Divisions are given below.

LRD has developed an excellent four-step risk-based budgeting model to prioritize O&M work packages for navigation:

1. This process first identifies components and activities (CAs) necessary to maintain the navigation.
2. Each CA is compared head-to-head to determine those that pose the greatest risk for unscheduled delays or closures.
3. The CAs are identified as to critical or noncritical risk with respect to halting navigation. Component condition is an important factor in determining risk. Condition rating uses the A–F metric shown in Table 6. Weight factors range from 100 for "Adequate" to 1000 for "Failed."
4. The head-to-head weightings are multiplied by the condition weight factors. This results in the Navigation Feature Risk Factor. A Condition Criticality Factor, which combines the criticality with the condition rating, is also used.

This process, plus considering economic impacts and a human expert adjustment (if needed), results in the prioritized list.

* The authors note that previous work by LRD and SWD demonstrated that prioritization schemas are effective in segregating the most important work packages according to current funding priorities; e.g. high vs. lower importance (Foltz 2001). However, they also discovered that it is far more difficult to create prioritization schemas with sufficient detail to accurately rank work packages within these groups. This capability is what is most needed; specifically, for ranking work packages near the funding cutoff.

Northwestern Division (NWD) uses an analytical approach based on risk probabilities to establish a critical infrastructure list. Annual loading frequencies, conditional probability of unsatisfactory performance (failure), annual probability of unsatisfactory performance, and consequence of unsatisfactory performance all combine to determine a relative risk ranking classification. A matrix combining the relative risk ranking classification and the annual probability of unsatisfactory performance results in 25 priority groups. Condition is considered within the conditional probability of unsatisfactory performance through a qualitative assessment of probability of failure (i.e., Very Low, Low, Moderate, High, Very High). Work packages are individually prioritized within each category by considering benefit/cost and the experience of the members of the critical infrastructure team. The team meets every 2 months or so, in part, to update the critical infrastructure list.

Screening for Portfolio Risk Assessment for dams

SPRA is used (or will be used) to support major rehabilitation prioritization. Rankings depend on the DSAC (see Table 7). Inasmuch as this is a new process, only just over 25 percent of respondents were familiar with it and none knew if or how any further prioritization (within DSAC category) was accomplished. While condition is an important consideration, as previously stated SPRA includes no standardized process for identifying distresses or evaluating condition. Condition is considered subjectively based on review of Periodic Inspection reports and other reports as available.

District/Division business decisions

One of the questions posed in the survey was to ask how condition information was used to support or justify business decisions regarding identifying, funding, and scheduling work and operating the infrastructure. The typical response referred back to work package, budgeting, and prioritization as discussed above. Inasmuch as the majority of the respondents represented the FDR business area, dam-safety-related issues were very prominent in overall decisionmaking. For example, decisions to correct dam-safety-related deficiencies ahead of other deficiencies are common.

Business decisions regarding work package funding is influenced by the ability to execute the work. Work may slip in priority and funding if it cannot be accomplished in the timeframe desired due to operations, inability to attain a contract award, or other reasons.

Business decisions affecting operations may result from condition-related problems. For example, the DSAC states that operating restrictions may be necessary until repairs are completed to reduce risk. A number of respondents stated that addressing risk (if not currently done, it will be in the near future) influences (or will influence) business decisions. The development and execution of a risk mitigation plan may be necessary if funding for repair is not available.

Sometimes work execution will cause a major disruption to operations, particularly navigation. To minimize future disruptions, sometimes lower priority work (e.g., work packages that could be deferred) will be included. This way, the backlog may be reduced to avoid having to do disruptive work for a few years.

Reporting (including data/information storage and flow)

Information flow is an essential element to an effective infrastructure asset management program. This includes information used locally at the project as well as at the District, Division, headquarters, and others. As discussed below, there are different means for providing information. Some of the respondents, not all, stated that condition information was provided to or specifically requested by "higher authority." Often this request is to support funding requests. "Higher authority" can, however, access and use condition information on its own. Much is available via the means described below, thus negating at least some of the need for special information requests. Presumably, different management levels require different condition information with higher level management requiring less detail. One respondent said that at one time "higher authority" wanted REMR CI information, but no longer.

Periodic inspection reports

The primary means for reporting has been and continues to be the periodic inspection report (ER 1995). These are relatively thick, comprehensive reports that address the inspection process, findings, monitoring data, photographs, analyses, and recommendations. Some reports are available electronically, via the Internet, and/or in the traditional hard copy form.

Dam Safety Program Management Tools (DSPMT)

Districts are using the DSPMT software (DSPMT 2008) to store and track inspection deficiency data, inspection dates, estimated repair costs, and actual repair costs.

Biannual reporting to Federal Emergency Management Agency (FEMA) on dam safety

One of the intended purposes of the inspection findings is to provide input for the biannual reporting requirements to FEMA on the Corps Dam Safety Program (ER 1995). This reporting is accomplished though the use of the DSPMT software. Major inspection findings are submitted based on a detailed, systematic technical inspection and evaluation as required (ER 1995). Thus, inspection information, as currently collected and reported, appears to also meet FEMA requirements.

Geographical Information Systems (GIS)

GIS are being introduced to display map locations where deficiencies exist. As examples, Jacksonville and Portland Districts as well as LRD are using or developing GIS reporting capabilities with varying features (e.g., "drill down" for details).

Work Item Tracking System (WITS)

The Tulsa District is using a WITS to store and report work package status. Among the data included are work item number, priority, description, criticality, cost estimate, scheduled start (FY and Quarter), scheduled completion (FY and Quarter), and business line (e.g., Navigation). Other Districts, Divisions, and headquarters also have systems for tracking work items.

Operating logs / Daily reports / Spreadsheets

Day-to-day operating data and equipment maintenance records are kept at the projects. Monitoring (instrumentation) data are typically electronically stored on spreadsheets at the Districts.

Facilities Equipment and Maintenance (FEM) system

The FEM asset management system was designed primarily for equipment maintenance that has been employed in the Northwestern Division at a variety of hydropower projects (Krahenbuhl 2006). FEM, in part, is a data

repository for equipment operating and maintenance standards, practices, and accomplishments. Rock Island District is a pilot site for FEM system implementation for navigation projects to help manage PM as well as create a partial asset management database for critical components. The LRD asset management initiative is looking to employ FEM, in part, for PM management so that the effects of PM on asset condition can be evaluated. The LRD FEM hierarchy and the components defined for condition assessment and prioritization (discussed above) are directly linked.

Personal knowledge

One respondent made the point that a critical “data storage” means was the personal knowledge that he and his colleagues had of the projects in his District.

5 Discussion and Recommendations

As was stated in the introduction to this report and as cited in the Acting Chief for Operations, Directorate of Civil Works memorandum (Appendix A), the Directorate is in the early stages of implementing asset management principles as a systemic means of managing CW infrastructure. In support of that work, this project involved conducting a telephone survey of various USACE personnel to gather information about current CW condition assessment approaches and evaluate these for suitability in an infrastructure asset management context. The approach was to first ascertain how inspections were being conducted on CW infrastructure and how inspection data were transformed into a measure of condition. Then, the usage of condition information in CW infrastructure asset management especially as it pertained to work package development, budgeting, prioritization, overall District and Division decisionmaking, and reporting was discussed. Those findings have been reported in Chapters 3 and 4 of this document. This chapter will analyze the findings and draw conclusions about how current inspection and condition assessment practices mesh with certain modern asset management principles. Several inspection and condition assessment recommendations are offered to strengthen the CW asset management process (both strategic and tactical decisionmaking) to not only meet the requirements of EO 13327 and the resulting FRPC guidelines, but also to meet the universal asset management goal of maximize infrastructure performance, consistent with need, at the lowest possible life-cycle cost.

Civil Works asset management challenge

Implementing a successful CW infrastructure asset management process poses a significant challenge. Some of the key factors that will influence success are briefly discussed below.

Magnitude and location

USACE has a large CW infrastructure portfolio, spread across many specific projects, located all over the United States. The sheer magnitude and physical separation of these assets virtually ensures that asset managers will not have first-hand knowledge and experience of the entire portfolio. Also, the types of CW infrastructure are diverse and they vary in complexity. Thus, a structured information flow rather than passionate pleas is

paramount for strategic decisionmaking. A common structure to that information, backed up with supporting documentation as necessary, will ensure that appropriate aggregation (or slicing) can occur to measure progress and success and to support certain strategic decision tasks such as budget formulation, budget allocation, and “big picture” prioritization.

Diversity of purpose

USACE CW infrastructure serves a variety of “customer” needs. This diversity of purpose is reflected in the business area organizational concept. How well the CW infrastructure supports those needs must be reflected through the usage of meaningful metrics appropriate for each business area and the entire organization.

Management complexity

The USACE CW organization is large and diverse. A brief description was provided in the introduction (Chapter 1). This diversity ensures that many different people in many different locations and organizational levels will be involved in the various CW infrastructure asset management activities and will be making various strategic and tactical decisions.

Project / District / Division uniqueness

Projects, Districts, and Divisions are not carbon copies of one another. Each has a uniqueness (e.g., type, size, mission, loading, history, needs, etc.) that must be reflected in CW infrastructure asset management decisions. Thus, the CW infrastructure asset management process must be flexible commensurate with the decisionmaking that is needed at all levels and across business areas.

Risk management

Risk management is inherent in any infrastructure asset management process. For certain CW infrastructure, however, risk takes on a dimension not normally found with most other infrastructure. This is because for certain CW infrastructure, the consequences of failure can be dire. For example, in the case of a dam or levee failure resulting in flooding, significant loss of life or property damage could result. Likewise, failure of a navigation lock would result in a service disruption that could have more severe economic consequences than the failure of other infrastructure such as highways or railways because of an inherent lack of route redundancy in the inland waterway system.

Inventory definition

A basic infrastructure asset management question is, "Just what is it that is being managed?" Often, managers feel that they have a good answer to this by simply referring to their property records (a.k.a. property record cards). The FRPC takes this approach by referring to a "constructed asset." For CW infrastructure the concept of a "constructed asset" is still being refined. It is likely that these assets will encompass such infrastructure as locks, dams, levees, etc. Certain aspects of asset management are appropriate at this level; however, this level of inventory is inadequate for the full spectrum of infrastructure management.

Appropriate "management units" must be defined at the component level, which is no trivial concept. Each "management unit" has its own unique life-cycle (due to type, material, usage, etc.) and/or importance to mission (criticality). (Note: For the purpose of this discussion, "management units" are undefined but may conceivably be aligned with project feature components or logical portions thereof. However, to differentiate "management units" from features or components, the term "section" will be used to denote a physical entity that is to be managed as a singular unit.)

The section is the heart of any structured infrastructure asset management process as it forms the basis for most decisionmaking. Thus, a project will consist of a collection of sections. Each one would be appropriately inspected, have its condition assessed, and have its work needs determined and costed, when needed. Work packages would address one or more sections. If gates are typically repaired as a group, grouping all gates in one section would facilitate management of this repair work better than having each gate as a separate section. Likewise, if gates are usually repaired individually, making each gate a separate section would facilitate management of this repair work better than one section for all the gates.

While LRD has not fully implemented a systematic method of determining sections, they embrace the concept in their approach to asset management. Condition ratings and prioritization are accomplished at the section (i.e., component in their application) level. The inventory data (e.g., condition index) required by the FRPC for a "constructed asset" (see Chapter 1 of this report) would consist of aggregated section data. (Note: FRPC is using the term inventory in a very broad sense. The term "attribute data" better describes FRPC requirements.)

Part of FEM implementation is the creation of an inventory database. This inventory and an infrastructure asset management inventory need not be the same, but they are related. FEM allows for the creation of an inventory hierarchy necessary, in part, to support a PM program. A PM inventory is generally much more detailed than is needed for the infrastructure asset management objectives described earlier. However, within the FEM inventory hierarchy (generally at the high end) there should be an inventory match to a defined asset management section. Thus, from an overall asset management perspective, the PM program is appropriately linked. A PM program is an essential part of an effective infrastructure asset management program. LRD is working towards this goal and is developing their hierarchy to ensure that linkage exists. The Rock Island District is also working to establish their FEM hierarchy similarly, but is limiting their inventory to critical components.

It is recommended that USACE develop guidelines for the creation of CW infrastructure sections. These guidelines will ensure consistency of information needed to support decisions, especially above the District level. This consistency includes component identification and nomenclature. Guidelines instead of standards are recommended to provide the flexibility needed to account for unique situations that are inevitable at various projects. These guidelines will likely vary by business area. Additionally, they need to have the ability to be logically aggregated to meet the FRPC requirements (if a given section is less in scope than a constructed asset) and also fit into the FEM PM hierarchy. Further, since the defining of FEM inventory is currently underway in some Districts, this recommendation needs to be acted upon soonest to ensure general consistency within USACE. The pioneering efforts of LRD and Rock Island District will serve as a starting point and may already have largely addressed these needs.

Reinventing inspection through a knowledge-based approach

Inspection and condition assessment are necessarily linked. That is; whatever approach is used to ascertain one or more condition metrics, it must be supported by the inspection process. Likewise, inspection should not simply be a "fishing expedition" to gather as much data as possible. Rather, the inspection and resulting condition assessment process must directly support the strategic "what, where, when, and budgeting" decisions as well as the tactical "how best" decisions for each section.

Currently, deficiency-based inspection data, of varying detail, are collected. As discussed in Chapter 3, the 5-year periodic inspections are the

most comprehensive, intermediate inspections are less so, and the informal inspections are even less. But, nonetheless, the inspection process is still focused on finding deficiencies. Deficiencies translate into work packages from which budgeting, prioritization, and other business decisions are made. This is the “job jar” approach to infrastructure asset management. While generally deemed “tried and true,” the “job jar” approach can and must be improved if USACE is to move forward with structured infrastructure asset management principles. Although none of the respondents believed that they have too much inspection information, this is a common engineering misperception. Unless all of the inspection information is needed to support current or future asset management decisions, some is unnecessary (i.e., too much). Any given inspection should not attempt to support all strategic and tactical decisions for each and every section. Decisions are dependent on where a section is in its life cycle because section “needs” vary over that life cycle. Strategic decisions require varying levels of detail, and tactical decisions require more detailed information than strategic ones require.

Meaningful inspections and assessments, at less cost, can be conducted to support the CW infrastructure asset management process. This is because typically one or more of the following occurs:

- During a 5-year inspection, all features in a project are inspected, although the formal interim inspections may target specific features.
- Inspection frequency is based on regulation requirements. This often leads to under-inspection and missed opportunities for optimal maintenance, repair, rehabilitation, or replacement decisions, thus resulting in penalty costs.*
- Occasionally, over-inspection is conducted that wastes inspection resources.
- The deficiency-based approach is designed to fill the “job jar.” But, due to funding delays and constraints, the scopes-of-work and cost estimates for the jobs in the jar are often rendered out-of-date prior to execution due to changed conditions, thus requiring a re-assessment at a later time.
- The deficiency-based approach to inspection is not conducive to an objective and robust condition assessment methodology. At best, it lends itself to a condition rating that limits the usefulness of the inspection data. This is discussed under “condition assessment” below.

* Penalty cost is the additional cost of doing work past the most desired time to do that work. It can be measured through the additional cost for repairs as well as any additional consequence cost (e.g., additional economic disruption).

USACE holds a patent (#7058544) for a "knowledge-based" approach to inspection (KBI). Originally developed for buildings, KBI combines a varying inspection frequency with different inspection types and level of detail (Uzarski et al. 2007). Unpublished accounts by ERDC-CERL in field testing and by contractors using these concepts have indicated significant inspection cost savings while satisfying the condition assessment needs to support infrastructure asset management strategic decisionmaking. The authors of this report believe that the concepts, with revisions, are applicable to CW infrastructure. It is recommended that the KBI concepts be explored for inclusion as a core principle in a structured CW infrastructure asset management process. The concepts are briefly explained below.

Inspection frequency

Rather than having a formal 5-year inspection and interim formal inspections of projects, each section in a project will be scheduled for a more aptly named "condition survey inspection" based on a series of variables. Some of these variables may include project importance, section importance, section expected service life (time to replacement or major rehabilitation), section estimated remaining service life, section maintenance life (time to maintain or repair), section remaining maintenance life, section rate of deterioration, condition standards and policies, failure risk, failure consequences, and maximum desired timeframe between condition survey inspections. The outcome of routine analyses of monitoring data (as is currently being done) will also factor in on determining inspection frequency. By using these variables in a decision tree, algorithm, or spreadsheet analysis, District level inspection planning will determine which sections in each project require a condition survey in a given year.

Certain sections would likely become exceptions. One exception is managing nonmaintainable sections (those where periodic replacement is the only viable work alternative, which generally involves two cases. The first case is a low risk situation where it can be run-to-failure with minimal service disruption at failure. Condition survey inspections are not needed in this situation, because the failure of the component itself indicates a work requirement. Work is accomplished when failure occurs. The other case is a high risk situation where the service disruption would be severe should failure occur. In this case, an inspection is scheduled at some point prior to the end of the expected service life for the purpose of confirming or re-estimating the remaining life. The goal is to replace the section before failure (thus avoiding the service disruption), but not too soon or value is lost. The inspection and subsequent section replacement timing (i.e., number

of years before projected failure) is based on the tolerable risk of service disruption resulting from the failure. Another exception would be when a catastrophic event (e.g., flood) occurs, which should trigger an inspection (as it does now). A third exception could result from a FEM trend analysis of O&M data. This analysis could trigger an inspection to determine if an overhaul or replacement is warranted. A fourth exception is when anomalies in monitoring data or trend data indicate a problem. This should trigger an inspection (as it does now).

By employing this methodology, some sections in a given project may require annual inspections whereas others may go several years without one (up to a maximum allowed frequency such as 5 years). The current interim formal inspection process is sometimes targeted to specific features. This practice is somewhat similar to what is proposed. Informal inspections would continue as they do now. A drawback to the KBI approach is that it can result in an unbalanced inspection schedule. Thus, within a given District, some years will be more inspection intensive than others. However, labor leveling, if needed, could be worked out.

Levels of inspection detail

Infrastructure asset management decisionmaking can be supported through a combination of strategic condition ratings and distress-type condition surveys. This combination is much more robust for strategic decisionmaking than simply gathering tactical deficiency type data. Both condition ratings and surveys can directly support one or more condition metrics.

Condition ratings can take the form of a limited number of letter grades (e.g., A-) with each grade defined by specific criteria. This approach easily lends itself to a checklist application for ease of use. An inspector would have a listing of sections to be inspected, and a rating would be applied to each using rules based on section complexity and size. Some of the rules would require the defining of an "inspection unit," which is merely a portion of a section (if the section is large). Normally the "inspection unit" will fall within the inspector's field of view (either what the inspector can see or the inspector's area of expertise). By dividing the section into "inspection units" a better condition assessment results (discussed below). Using this approach yields coarse condition information, but few details, if any, will be known about what is actually wrong with the section. However, the strategic decision to be made often does not require information about what is wrong. Engineers and/or decisionmakers are "conditioned" to be-

lieve that they always need information about what is wrong, but sometimes they do not. For example, if the section is not in pristine condition, but not demanding maintenance, repair, or rehabilitation within the planning cycle, having information about what is wrong is “nice-to-have,” but not essential. There are exceptions to this, of course. Condition ratings will be discussed further below within the context of condition assessment.

Distress surveys are more detailed and encompass recording pre-defined distress types, density, and severity levels. They are more expensive than strategic condition ratings at the component, feature or project level, but distress surveys also provide details of what is wrong. Rules can be established to improve accuracy, repeatability, and significance of the resulting condition metric. The same “flags” could be made as discussed above if not addressed in the severity level definitions (which is the preferred method). Condition ratings and distress surveys are most often used in asset management systems.

Detailed deficiency-based inspections best serve tactical decisionmaking. There is a point in the infrastructure asset management process (i.e., answering the “how best” question) when condition assessment, per se, is no longer necessary. This is because the decision has already been made that maintenance, repair, or rehabilitation work is needed in the near future. What is required is an analysis of the various alternatives that will correct the problem and the details (sufficient scope to plan the execution) of the selected alternative. Deficiency-based inspections serve these purposes and, in the best circumstances with a fully developed Asset Management program including parametric cost estimation, they need to occur only in conjunction with a work execution plan. Thus, the “job jar” could become a result of the strategic decisions made through the infrastructure asset management process; not the precursor to it (which is what USACE is doing today).

Condition ratings, distress surveys, and deficiency-based inspections all have their place, especially when coupled to inspection frequency (discussed above). The key to effective infrastructure asset management is to perform the most appropriate inspection type at the right time. That is the whole idea behind KBI. A further discussion on the differences between distress and deficiency-based inspections and asset management can be found elsewhere (Uzarski 2006).

Engineering investigation

There is a difference between "inspection" and "engineering investigation." Sometimes an inspection (any inspection) does not reveal enough information about a perceived or actual problem. Any time an inspector indicates uncertainty as to a problem, further engineering investigation is needed. This generally would include a site visit and enough investigation and analysis to eliminate the uncertainty. The preliminary condition assessment may be confirmed or may require an adjustment (up or down).

Condition assessment

USACE is practicing different forms of condition assessment to meet CW infrastructure asset management (including dam safety) needs. These include the FRPC condition index, urgency and criticality approaches, and various condition and performance ratings. A discussion of each follows along with recommendations for improving condition assessment that will enhance strategic infrastructure asset management decisionmaking.

Federal Real Property Council Condition Index

As stated in the introduction to this report, the FRPC in their guidelines (FRPC 2004) has established a condition index as an asset management mandatory data element. They define this index as CI = 1 – (Repair Needs Cost) / (Plant Replacement Value) x 100. Repair needs encompass all that is needed to restore a constructed asset to its originally intended design, efficiency, or capacity. Plant replacement value is the cost of replacing the asset at current prices. This condition index is a derivative of the generally known Facility Condition Index (FCI). The FCI is defined as FCI = (Repair Needs Cost) / (Plant Replacement Value). The origin of the FCI is unknown, but its usage can be found beginning in the 1970s. With the FCI, a score of 0 is best. With the FRPC CI, a score of 100 is best.

Inasmuch as the FRPC has listed this CI as one of their data elements, it is likely that it will be implemented within the USACE CW infrastructure asset process. While this may satisfy FRPC guidelines, it is not particularly useful for infrastructure asset management and its value as a condition metric is questionable. Some of the reasons are:

- The plant replacement value (i.e., denominator) changes annually due to market forces and differently in different geographic locations.
- The repair needs cost (i.e., numerator) is highly dependent on the inspection process, especially what the inspector considers a "deficiency."

- Effort must be expended to compute a cost for the repair, even if a repair cost is not needed for current strategic decisionmaking needs.
- The resulting CI is highly dependent on the accuracy of the cost estimate for repairs.
- Combining the effects of the above, it is likely that the CI will change from one year to the next (up or down) simply due to adjustments in the above estimates (especially if only the numerator or denominator change), even though the actual material condition remains unchanged.
- Due to the inevitable fluctuation in CI due to cost change, tracking condition trends becomes problematic.
- There are no clear definitions as to what the CI actually represents other than that the lower the number is; the worse the condition is.
- While some users of the FCI have attempted to provide significance to FCI ranges, these are unfounded and not verified through unbiased research.
- Although the metric is called a "Condition Index," by definition it encompasses more than condition (e.g., it also includes modernization).
- Its practical significance as an asset management decision-support metric is unknown.
- Acceptable CI values should vary by infrastructure type and feature, but these acceptable CI values are unknown.
- Condition standards, as measured by the CI, are undefined.

On the positive side, the FRPC CI is relatively easy to obtain because it is easily derived from deficiency-based inspections and, from an overall Federal perspective, it provides a common metric across all agencies and infrastructure. However, even though it is a necessary reporting metric, USACE should employ metrics meaningful to CW infrastructure asset management. The FRPC guidelines encourage this. These opportunities are discussed further below.

The FRPC guidelines require the use of the FRPC CI, but they also allow agencies to use other condition measures. Interestingly, the example of an agency-specific performance measure used in the guidelines is the FCI. Inasmuch as the FRPC CI and the FCI are essentially the same metric, the use of the FCI as an FRPC example is puzzling. This same example is expanded to say that a certain percentage (2 percent) of replacement value is being reinvested. While this 2 percent is shown for illustrative purposes, this approach should be viewed with extreme caution within USACE CW. The Building Research Board (BRB 1990) states that an appropriate

budget allocation for routine maintenance, repair, or rehabilitation will be 2–4 percent (minimum) of the replacement value. The Federal Facilities Council (FFC 1996) expands on this by explaining the kinds of work that are included in the 2–4 percent and what kinds are not. Points to keep in mind are:

- Four percent is 100 percent more than 2 percent. Thus, a wide range is recommended by the BRB. When budgets are tight, a tendency is to use the low end of the range under the mistaken belief that funding is within an accepted guideline.
- These values were established under the presumption that they predominately applied to buildings.
- The actual percentage is a function of building use. Certain buildings (i.e., hospitals) demand more funding than others (i.e., warehouses).
- Budget needs will vary from year-to-year because maintenance, repair, or rehabilitation needs are cyclic.
- Chronic under funding will increase budget needs (i.e., the percentage will increase) over time.
- The value of using and/or reporting such percentages for CW infrastructure is unknown.
- A structured, meaningful condition assessment program is essential to properly establish budget needs for any given infrastructure asset in any given year.

The above points all serve to illustrate serious issues with the FCI approach (including the FRPC CI derivative) to condition assessment and usage in infrastructure asset management. Thus, although the FRPC CI is a required inventory data element and must be reported, as such, it is recommended that USACE not use this metric for any other infrastructure asset management purposes.

Urgency and criticality

The telephone survey conducted as part of this research revealed that the urgency for repair; the criticality of the feature to safety, failure risk, and/or operations; the consequences if repairs are not made; and a cost are viewed by some to be a de facto condition assessment. However, urgency and criticality (importance) are not condition or performance metrics. Urgency and criticality are important metrics for use in asset management decisionmaking, particularly when coupled to a consequence analysis; however, they are distinctly different from a pure condition state. For example, two features may be in the exact same physical condition

state, but one may warrant repair sooner (i.e., be more urgent) for a variety of reasons. Likewise, should those same two features fail; the consequences could be very different (i.e., one is more critical than the other.) Thus, urgency, criticality, and condition are not the same. It is recommended that USACE provide consistent definitions for the meaning of words such as condition, function, project, severity, performance, risk, criticality, and urgency (and others) to ensure a consistent usage in a structured CW infrastructure asset management process. Criticality, as a separate metric from condition, is discussed further below.

Condition and performance ratings

The telephone survey revealed that the term "condition assessment" is commonly used to describe the outcome of the inspection process. However, the approaches discussed in Chapter 3 of this report illustrate that a combination of condition and performance assessments are what is actually being practiced. Project ratings, component ratings, and the SPRA, shown in Tables 5 through 7, respectively, are actually better described as performance ratings than condition ratings. On the other hand, the inspection narratives and experience-based ratings more aptly address condition, but since the ratings are loosely defined, they could encompass both condition and performance. A common thread, as condition assessment is currently being practiced, is that it is rooted in a deficiency-based inspection approach with a heavy reliance on the skills, expertise, and experience of inspectors and evaluators (if different from inspectors). While skill, experience, etc. are powerful, there are drawbacks (see above discussion for inspection). The significance, quality, repeatability, consistency, and robustness of the condition (or performance) metric is only as good as the inspection process and the inspectors that feed it.

Condition assessment processes are relatively weak for infrastructure asset management. As currently practiced, the assessments can be uneven because the process is rooted in a subjective (artful) approach (see discussion in the introduction). The goal should be to base infrastructure asset management on science and as much objectivity as possible, but recognizing that there is always a need for skill, expertise, and experience in the process. The component rating approach (see Table 6) is the strongest of the various processes because it targets components, thus providing more granularity to the overall assessment process. The feature rating approach can be significantly strengthened by employing inspection units (discussed above), coupling it to a numerical index, and differentiating between condition and functionality (discussed below).

Improving performance assessments

Infrastructure performance measurement should be a desired metric for USACE CW because it addresses more than just condition and such a metric would address how well the infrastructure is meeting (or will meet) its total requirements. Performance can be evaluated more objectively and consistently than it currently is (see discussion above) if it is divided into two elements: condition and functionality. This dual approach has been applied successfully to buildings (Clayton and Uzarski 2005).

Condition element

The first element to performance assessment is condition assessment. Condition assessment, used correctly in this context, is limited in scope to addressing actual physical degradation. Degradation is ongoing, and is corrected or mitigated through maintenance, repair, or rehabilitation. Degradation may advance somewhat slowly over time due to mechanical, biological, and/or chemical attack. These degradation mechanisms are ever present due to usage and climatic/environmental exposure. Often, the degradation rate accelerates over time. Such degradation can be modeled, tracked, and predicted through the usage of an appropriate condition metric.

Sometimes damage events occur that add to the degradation. Damage may occur from a variety of sources and is generally unpredictable in scope, location, and when it may occur. From an asset management perspective, funds are sometimes budgeted and held in reserve should an event occur that warrants urgent action. The amount of funds budgeted are often based on experience.

The collection of data regarding degradation and damage is the purpose of inspection. A KBI approach to inspection lends itself to the collection of these data.

Metrics are needed for consistent measurement of condition. The measurement scales must be such that they are the right granularity to serve multiple functions. They must not only measure condition, they must also permit the measurement of a degradation rate, and be capable of being "rolled up" and/or "sliced and diced" to provide condition summary information at the project, District, and Division levels or even higher. Degradation rate is an often overlooked metric, but there are instances when it is at least as important as the actual condition, because it should influence

the timing for maintenance, repair, or rehabilitation. At higher levels, it can show if budgets are sufficient to "hold condition" or measure consequences of budget decisions.

While a descriptor (e.g., good, fair, poor) or letter grade (e.g., A, B, C) type scale (such as those currently used) will meet the requirements for assessing condition, these fail in the capability to compute degradation rates, roll-ups, or consequence analyses. Even if numbers are used instead of letters (e.g., 1, 2, 3), while a rate could be mathematically computed, the granularity of the scale is not sufficient to provide meaningful results. However, by using enough "inspection units" and an appropriate number of condition rating choices (see above discussion on condition), the inspection granularity is improved and a more robust numeric condition measure can result. For example, assume that a section consists of four individual miter gates. Each gate might be rated 1 though 5 (integers), but the average condition of the gate section could be taken to at least one decimal point (x.x) giving a ten-fold improvement in condition assessment measurement granularity.

A numeric condition scale is recommended for use in CW infrastructure asset management. An appropriate range should be researched and be directly linked to the recommended KBI inspection process recommendation described above. The scale can and should be divided into an appropriate number of ranges; each having a specific meaning. This would provide significance to what the measurement means (which is something that the FRPC CI fails to do). Other benefits to numeric condition scales are described in Foltz and McKay (2008).

Parametric cost models can be developed that translate numeric condition measures (and appropriate inventory data) to a repair cost. Such models are rough, at best. They can serve as the numerator for the required FRPC CI calculation and may be sufficiently accurate for planning purposes. These parametric models are useful and powerful tools in an asset management program, but creating and applying them to CW infrastructure repairs may prove difficult to assess. Infrastructure such as locks, training dikes, rubble mound coastal structures, and hydropower units will be difficult. Dams may be even harder. Adequate parametric repair cost estimate models will allow for delay of the more expensive but necessary deficiency-based cost refinement until later in the work planning process. The parametric cost models also support the usage of a "penalty cost" metric. Penalty cost is the additional cost of doing work past the optimal time to do

that work. It can be measured through the additional cost for repairs as well as any additional consequence cost (e.g., additional economic disruption). The development of parametric cost models based on the numeric condition scale is recommended.

Functionality element

The second element to performance assessment is functionality assessment. The functionality state relates to the suitability of the infrastructure to function as intended and required for the mission. The functionality state is distinct and independent from the physical condition state. Functionality loss results from general obsolescence due to changes in: user requirements, technology, and laws, codes, or regulations (Grussing et al 2008). For example, a lock may not have sufficient capacity to handle barge traffic levels or tow sizes. Another example may be that a levee was designed to protect against a 100-year flood event (with an assumed water level elevation), but over time data have shown that elevation to be inadequate. In both cases, the physical condition may be pristine, but work actions are necessary.

Functional loss is unlike condition loss. Functional loss occurs in steps — some large, some small — depending on the change. Evaluating functional loss is different from inspection and condition assessment. No functional loss is assumed as long as no requirements change. Thus, functional assessments are generally not required unless a change occurs and then the reduced or enhanced function remains constant until further change occurs. Often, these evaluations are performed in the office and only occur on an “as needed” basis such as when design standards change. (This is similar in philosophy to the SPRA process.) Inspection, if necessary, is generally limited to verification of what exists (e.g., presence, size, capacity) and what is proposed. A series of functionality rating charts similar to that shown in Table 6 can be developed to perform these assessments. A given chart would address one functionality aspect (Note that these would need to be developed along business lines) and would have a sufficient number of rating categories to properly address that aspect. The number of categories for a given aspect could be as few as two (i.e., yes or no). Functionality assessments will require skill and knowledge to implement. However, the process would necessarily evaluate function in a structured way. Improved consistency and repeatability will result.

Functional assessments can be accomplished at the project, feature, management unit, and section levels because certain aspects of obsolescence

occur simultaneously to multiple features or sections. Thus, the appropriate level must be evaluated. Any subordinate levels inherit the results of a higher level evaluation.

A metric is needed to measure functionality. A scale similar to that developed for condition is recommended, but it will be somewhat less robust. A rate of obsolescence is rather meaningless, and the roll-up aspect should probably be limited to a project or to some other meaningful level. The value of having similar functionality and condition scales is that it facilitates merging both assessments into a performance measure (discussed below). The scale can and should be divided into an appropriate number of ranges; each having a specific meaning. There are challenges to accomplishing this. Where probability of failure is the primary functional metric, it will be difficult to make similar condition and functional scales. Combining functional considerations such as probability of failure, efficiency, and effectiveness may also be difficult.

Performance Index (PI)

As stated above, performance measurement should be a desired metric for USACE CW because it addresses how well the infrastructure is meeting (or will meet) its total requirements. Performance can be measured by combining condition and functionality into another metric. Using the same numeric scale as condition and functionality, an appropriately weighted average can be computed that measures performance. The development of a PI is recommended. The PI would add another metric to the suite of metrics that greatly enhance the USACE CW asset management posture. The PI would also support the infrastructure asset management development work underway at LRD with the SPRA process.

Real-time assessments

An inherent problem with condition assessment (much less so with functionality assessments) and hence performance assessments is that the assessments become out-of-date. As a result, infrastructure asset management strategic decisions are often based on stale information. Fortunately modern infrastructure asset management tools can overcome this problem. Through the use of the metrics described above, future condition and performance can be predicted through the development of analytical models. Penalty costs can also be estimated. Future functional predictions are more difficult to predict (if at all), but “what-if” functional assessments can

be made should proposed changes to user requirements, laws, regulations, etc. occur.

Through the use of analytical prediction models, real-time assessments occur by taking the most recent assessment information and making a prediction of condition, functionality, and performance as of "today." The models are dynamic such that actual assessment findings will be compared to the predicated values as of that date. The models would self-correct accordingly. As more data are collected, the models become better. The same model can be used for consequence analysis to any future time. ERDC-CERL has a patent pending for such models. It is recommended that the ERDC-CERL analytical prediction models be evaluated for application to USACE CW infrastructure and, if found to be valid, that they be incorporated in a structured CW infrastructure asset management process.

Criticality measures

The notion that condition and criticality are not the same was discussed above. Criticality is a descriptor that can be applied to different infrastructure levels. The FRPC considers criticality as one of their inventory elements. It is their performance measure #3. They call it "Mission Dependency" and they categorize the "constructed asset" to be mission critical, mission dependent – not mission critical, or not mission dependent (FRPC 2004). This descriptor may satisfy a certain management requirement for an asset as a whole, but it can be improved and applied to sections to aid in the infrastructure asset management decisionmaking process. LRD uses a simple "Critical" or "Noncritical" to denote the potential to halt navigation, which is reasonable but possibly limiting because "potential" could have a broad interpretation. The U.S. Navy has developed a Mission Dependency Index (MDI) that is applied to components of military facilities (NFESC 2008). This index, which is totally independent of condition, uses a 1-100 scale with 100 being the most critical. MDI usage focuses management attention on those components most important to mission. It is recommended that the MDI development process be studied for adaptation to CW infrastructure.

Prioritization

Prioritizing work packages for budgeting planning and/or budget execution is the norm. Different approaches to this are being conducted in different Districts and Divisions (see discussion in Chapter 4). The point rankings developed by MVD and the analytical approaches taken by LRD

and NWD are noteworthy. All use an objective approach tailored to their Divisions and represent sound CW infrastructure asset management practice. As stated at the beginning of this chapter, the projects, Districts, and Divisions are not carbon-copies of one another. Each Division, as well as their Districts and projects, have a uniqueness that must be reflected in the CW infrastructure asset management decisions that must be made. Arguably the most important decision is determining what work gets funded and what work does not in a given year.

Five criteria have been identified as key considerations in the prioritization process (Oliver et al. 1998). These are condition, performance (condition and function), risk/reliability, economics, and business priorities and policies. Each criterion should be considered in the decision process, but the importance of each in determining priority will vary based on the type of work. There may also be sub-criteria, making the prioritization process even more difficult. For example, economics should be based on a myriad of costs and benefits. Table 9 lists costs and benefits of infrastructure repair. The list should be looked upon only as representative of the multitude of possible considerations from some of the business areas. Note that, even for items that are quantified in dollars, all dollars may not be equal. For example, damages to others may be a higher priority than fee generation.

The prioritization processes would all be enhanced with more and better metrics and an ability to perform “what-if” consequence analyses with measurable outcomes.

It is recommended that a shift from prioritization-based work package rankings to an optimization-based (i.e., maximize or minimize desired outcomes) process be considered within a “next generation” evolution of CW infrastructure asset management. By employing operations research techniques and methods, work packages can be selected based on an objective function (e.g., maximize dam safety, minimize penalty cost) and considering various constraints (e.g., budget). SPRA is a step in this direction. Often, the results are surprising and nonintuitive. Prioritization can be done at the Division level to maximize Division benefits and refined at the District level for execution.

Table 9. Costs and benefits of infrastructure repairs.

Downstream economic damages
Persons at Risk & Loss of life
Annual benefits (assets protected)
Federal assets protected
Customer delays
Scheduled closure
Unscheduled closure
Maintenance and repair optimization
Local-local commerce
Local-distant commerce
National commerce economics
Commercial fishing
Recreation
Fee generation
Operations costs
Environmental damages
Worker safety
User safety
Repair cost
Repair effectiveness

Standards

It is unreasonable to expect the entire CW infrastructure portfolio to remain in a pristine condition, functional, or performance state. Standards are needed to address the minimal levels of condition, functionality, and performance. These standards should be based on operational needs, allowable risk, and other germane factors. Not every feature or component needs to be maintained or repaired to the same standard. But, standard compliance needs to be measurable.

Often, standard compliance is handled at the time of inspection. Inspectors, through their judgment, may not record a deficiency (or even consider a deviation from pristine a deficiency) if the resulting condition is at or above a required or desired standard. This is another weakness of the deficiency-based approach to inspection, especially if standards are not defined (or ill defined).

However, a structured infrastructure asset management practice requires that standards be established and measured against appropriate metrics. LRD is making standards an essential element to their asset management practice. Table 6 is used for their condition assessment process and it is also used as a standard. The various District operations chiefs within LRD

collaborated to define the minimal standards. For example, a given component may have a current condition level of “B.” But the established standard for that same component may also be a “B.” Thus, this component is in compliance with the standard even though it is not pristine. This is an excellent asset management practice.

The development and usage of additional metrics as described above will further enhance the usage of standards. Standard levels will need to be established for these metrics.

Risk management

Dam safety is clearly an emphasis within USACE. A number of the individuals interviewed are Dam Safety Program Managers. These individuals as well as the Dam Safety Committees (ER 1110-2-1156) ensure that dam safety issues are identified and receive adequate attention, including proper prioritization for rectification. The SPRA initiative is excellent for addressing “big picture” dam safety issues.

Dam safety management is all about risk management. Bowles (2006) describes a shift from portfolio risk assessment to portfolio risk management. He says that this approach is being applied by USACE. Basically it combines engineering standards with risk assessment methods to provide for a systematic means to identify, estimate, and evaluate dam safety risks. As previously stated, SPRA is a step towards optimization. While standards help identify what needs to be done, risk management allows optimization by indicating what should be done first to make the greatest reduction in portfolio risk.

As discussed earlier in this chapter, risk management is inherent in any infrastructure asset management process. The KBI process, condition assessment, functional assessment, and performance metrics described earlier, not only fully support both risk management and asset management, but they enhance both. Risk is considered as part of the proposed inspection frequency and type; addressed as part of the assessment process; and in budgeting and work prioritization.

Risk encompasses more than just dam safety. Every business line carries an element of risk associated with a service failure. The applicable elements should be appropriately incorporated as discussed above.

FEM and Infrastructure Asset Management

Inasmuch as a solid preventive maintenance program has proven worth, it must be an essential element to an infrastructure asset management program. As discussed above, FEM is being used or is in the process of being implemented in various Districts. When fully engaged, FEM will address the aspects of PM plus do much more. It can schedule inspections, serve as a repository for inspection data, provide trend analysis using monitoring data, and provide overall asset management decision support. A weakness, though, is an inability for FEM to perform mathematical analyses in support of generating condition or functionality measures from inspection data, predicting condition, and performing consequence analyses. Thus, to move forward in implementing asset management principles, USACE needs a robust software platform with database capability to perform these functions. Discussions with LRD revealed that FEM is to be the central platform for their asset management initiative. It will interface with other USACE systems. As the computer "software" aspects for CW infrastructure asset management evolve, it is recommended that they incorporate the ability to perform the necessary condition assessments and analyses and have appropriate query-driven reporting features to provide appropriate summary or detailed information commensurate with strategic and tactical decisionmaking.

"Personal knowledge" shortcomings

Currently, the success of CW infrastructure asset management relies on the skill and experience of USACE personnel. Many of the persons interviewed prided themselves in their personal knowledge (or the knowledge of their subordinates) of project conditions. This is a testimonial to the quality and professionalism of USACE personnel.

Unfortunately, most of this knowledge resides within the persons themselves. Thus, this knowledge is limited to the person's personal horizon. Current USACE practices do not have the capability to incorporate most of this personal knowledge in higher level asset management decisions. Also, people retire, move to other positions, leave Federal service, and die. When that occurs, knowledge is lost. The retirement of personnel with the "stored data" is frequently referred to in the USACE community. Many people with critical knowledge not available in reports have already retired.

Structured asset management principles require free information flow and an ability to harvest historical information. While this is improving (see discussion on reporting in Chapter 4), there is plenty of room for improvement. The power of information (data and analysis results) is crucial to asset management success. However, the gathering and storage of that information comes with a cost. The temptation to gather a wide variety of data on the notion that it may be useful to someone sometime must be resisted. Only those data elements necessary for supporting strategic and tactical decisionmaking (beyond those mandated by FRPC) must be defined and made part of any structured asset management approach. It is recommended that data elements necessary for supporting strategic and tactical decisionmaking be carefully defined. Perhaps this task can be assumed by USACE Centers of Standardization, Communities of Practice, or ERDC.

Incentives for good management

There is a perception by many within USACE (and elsewhere) that good asset management may result in budget cuts because there is a "worst first" mentality to budget allocation. Money follows problems not problem prevention. Also, some managers are in a "comfort zone" and are reluctant to embrace new ideas that would nudge them out of that zone. This issue is common when adopting asset management principles. This human factor must be recognized because it can translate into resistance to change, implementation delay, or even failure. USACE should consider adopting an objective reward system based on measured success to successfully embrace and adopt structured asset management principles.

6 Summary of Recommendations

The list of recommendations below summarizes those recommendations provided in Chapter 5:

- USACE should develop guidelines for the creation of CW infrastructure sections.
- The KBI concepts should be explored for inclusion as a core principle in a structured CW infrastructure asset management process. Inspections should be primarily driven by need and only minimum requirements set by the calendar.
- Although the FRPC CI is a required inventory data element and must be reported, as such, it is recommended that USACE not use this metric for any other infrastructure asset management purposes.
- USACE should produce precise definitions for the meaning of words such as condition, function, performance, criticality, and urgency to ensure a consistent usage in a structured CW infrastructure asset management process.
- A numeric condition scale is recommended for use in CW infrastructure asset management.
- The development of parametric cost models based on the numeric condition scale is recommended.
- A metric is needed to measure functionality. A scale similar to that developed for condition is recommended, but it will be somewhat less robust.
- The development of a PI is recommended.
- The ERDC-CERL analytical prediction models should be evaluated for application to USACE CW infrastructure and, if found to be valid, they should be incorporated in a structured CW infrastructure asset management process.
- The MDI development process should be studied for adaptation to CW infrastructure.
- A shift from prioritization-based work package rankings to optimization-based (i.e., maximize or minimize desired outcomes) rankings should be considered within a “next generation” evolution of CW infrastructure asset management.
- It is recommended that the MDI development process be studied for adaptation to CW infrastructure.
- A shift from prioritization-based work package rankings to optimization-based (i.e., maximize or minimize desired outcomes) rankings

should be considered within a “next generation” evolution of CW infrastructure asset management.

- As the computer “software” aspects for CW infrastructure asset management evolve, it is recommended that the ability to perform the necessary condition assessments and analyses be incorporated and the appropriate query-driven reporting features be included to provide appropriate summary or detailed information commensurate with strategic and tactical decisionmaking.
- It is recommended that data elements necessary for supporting strategic and tactical decisionmaking be carefully defined. This task can perhaps be assumed by USACE Centers of Standardization, Communities of Practice, or ERDC.

7 Summary and Conclusions

Districts have some guidelines for condition assessment, but are largely independent and "do their own thing" when doing "condition assessment." Districts depend largely on experience and familiarity with the condition, behavior, and performance of the infrastructure. The methodologies are mostly subjective.

Condition assessment does not have a consistent definition across USACE. Often the assessments are a mixture of physical condition, function, and identification of deficiencies.

Condition-related decisions work relatively well at the tactical level. Subjective methods based on experience work best at the project level and within a District's business line level.

Currently condition data are not consistent enough to be used at a strategic level across Districts or business lines within the context of asset management. Using a standard method to collect, organize, and quantify the data is critical for strategic purposes.

The current condition reports are primarily descriptive with some measured data (mostly instruments) but very few quantified ratings. This makes it difficult to track changes and determine deterioration rates.

Some of the recommendations stated herein may prove difficult to implement and progress may be slow. While the recommendations represent sound asset management practices, there are some things that can be learned only by developing, implementing, and refining the necessary tools.

Acronyms and Abbreviations

Term	Spellout
ANCOLD	Australian National Committee on Large Dams
ANSI	American National Standards Institute
APWA	American Public Works Association
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BCI	Building Condition Index
BRB	Building Research Board
CA	component and activity
CERL	Construction Engineering Research Laboratory
CI	Condition Index
CSCI	Component-Section Condition Index
CW	Civil Works
DC	District of Columbia
DOD	Department of Defense
DSAC	Dam Safety Action Classification
DSPMT	Dam Safety Program Management Tool
DX	Directory of Expertise
EC	Engineer Circular
EO	Executive Order
ER	Engineer Regulation
ERDC	Engineer Research and Development Center
FCAT	Facility Condition Assessment Team
FCI	Facility Condition Index
FDR	Flood Damage Reduction
FEM	Facilities Equipment and Maintenance
FEMA	Federal Emergency Management Agency
FFC	Federal Facilities Council
FRPC	Federal Real Property Council
FY	fiscal year
GIS	geographic information system
GPR	ground penetrating radar
HQ	headquarters
IFMA	International Facility Management Association
KBI	knowledge-based inspection
LRD	Great Lakes and Ohio River Division (LRD)
MDI	Mission Dependency Index
MVD	Mississippi Valley Division
N/A	not applicable

Term	Spellout
NFESC	Naval Facilities Engineering Service Center
NSN	National Supply Number
NWD	Northwestern Division
O&M	operations and maintenance
OMB	Office of Management and Budget
PCI	Pavement Condition Index
PFMA	Potential Failure Modes Analysis
PI	Performance Index
PM	preventive maintenance
REMR	Repair, Evaluation, Maintenance, and Rehabilitation
SPRA	Screening for Portfolio Risk Assessment
SR	Special Report
TR	Technical Report
USACE	U.S. Army Corps of Engineers
WITS	Work Item Tracking System

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Appendix A: CECW-CO Survey Announcement Memorandum

DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS
WASHINGTON, D.C. 20314-1000

CECW–CO NOV - 2 2007

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Infrastructure Condition Assessment for Asset Management

1. The Directorate of Civil Works is in the early stages of implementing Asset Management principles as a systematic means of managing infrastructure. Expected benefits include the establishment of standards and criteria that will facilitate operations and maintenance (O&M) budgeting, scheduling, life cycle performance optimization, and risk reduction. A critical piece of this puzzle is condition assessment. The U.S. Army Corps of Engineers must have a complete picture of the practices used for assessing condition and performance and best practices must be identified.

2. During the next few months, telephone surveys will be conducted to identify existing condition assessment practices and recommendations for what is needed. The surveys are intended to ascertain what kinds of condition data are collected and how, specifically, condition data are used in business decisions. These surveys will be conducted mostly at the district level. Conversations might last approximately one hour.

3. If you are called, please cooperate and be willing to answer the survey questions, share information, and identify more personnel who can help us build a picture of current practices. This process is being managed by the Engineering Research and Development Center Construction Engineering Research Laboratory POC's Mr. David T. McKay, (217) 373- , david.t.mckay@erdc.usace.army.mil, and Mr. Stuart D. Foltz, (217) 373- , stuart.d.foltz@erdc.usace.army.mil. The contractor is Dr. Donald R. Uzarski, (217) 398- , duzarski@aol.com.

MARK F. SUDOL, D. Env.
Acting Chief, Operations
Directorate of Civil Works

Appendix B: Survey Questionnaire

Part 1

These questions were asked of all survey respondents:

1. What is your name? (Note: This is a confirmation question).
2. What District do you work in? (Note: This is a confirmation question).
3. Are you in a District, field, or project office?
4. In what Division (Engineering, Operations, etc.) and branch/section do you work?
5. What are your title and primary duties?
6. Are you an engineer? Y / N
7. What is your role in the facility asset management process (i.e., inspection -> condition assessment -> O&M work package creation -> rehabilitation project development -> work/budget prioritization -> execution, or other business decisionmaking tasks?
8. Within the Flood Risk Management business area, what infrastructure is included that especially serves a multipurpose (e.g., navigation, water supply) use?
   a. Embankment dam?
   b. Concrete gravity dam?
   c. Dam gates?
   d. Operating equipment?
   e. Levees?
   f. Other (list)?

For the following questions, if the interviewee is not involved or does not know how a given task is done, ask if he/she knows who is involved or does know.

9. Do you make large scale budget decisions? If so, how important is condition information to you or others in making these decisions?
10. How is the inspection and condition assessment information used to develop O&M budgets, work packages, and/or rehabilitation projects?
11. If condition data or metrics are not used, how are decisions made regarding budgeting and work package development (e.g., experience, past trends, etc.)?
12. How many work packages are developed in a given year within the Flood Risk Management business area of your project? How about the project as a whole? District?

13. What condition information is provided to or asked for by higher levels of authority (i.e., District, Division, or headquarters [HQ])?
14. Are condition data or metrics used to evaluate and prioritize work packages within the Flood Risk Management business area? District? Division?
15. If condition data or metrics are not used, how are the work packages prioritized?
16. How are the condition data used to support or justify District business decisions, made at the Project or District levels regarding identifying, funding, scheduling maintenance, repair, and construction work, and the operation of District infrastructure?
17. Are you aware of any noteworthy inspection or condition assessment approaches, techniques, or methods used on infrastructure that is not included in the Flood Risk Management business area?
18. Are you aware of any District or Division developed “best practices” for inspection or condition assessment?
19. Are condition assessment metrics that are applicable (i.e., apple-to-apple) among all infrastructure important? Why or why not?
20. Is there anyone else you can refer me to who could add to this discussion (e.g., people involved with inspection, condition assessment, preparing or submitting O&M work packages or budgets, evaluate work packages or budgets, prioritize work packages, or execute work? If so, who are they and what are their telephone numbers?
21. Is it ok if I call you again, if necessary, to clarify issues or expand the discussion?

Advise interviewee that they should feel free to call Dave McKay (217-373-xxxx) or Stuart Foltz (217-373-xxxx) at ERDC-CERL if they have any questions, concerns, comments, etc. You may also feel free to contact me at 217-398-xxxx.

Part 2

If applicable, these additional questions were asked:

1. How often is it inspected? Note: Include all inspections
2. Who (organizationally) is doing the inspections?
3. What is the primary method used for gathering inspection data?
4. Are there any secondary methods used? If so, what are they?
5. What specific data are collected?
6. Are there different levels of inspection? That is, do different inspections entail different levels of detail, accuracy in measurement, frequency, and/or labor expenditures? If so, what are they and how do they differ?

7. Do you have the level of inspection detail that you need? Do you have too much detail?
8. How are monitoring data used?
9. What triggers special studies (e.g., liquefaction)? Then what (e.g., How are they scheduled, the results used, etc.).
10. If asked, “What condition are your dams, levees, gates, various components, etc. in?” what would you say? How do you know? (Metrics?)
11. Would you consider the inspection and condition assessment process “well developed” (i.e., in use for a long time, in routine practice, and well accepted) (e.g., follows an ASTM standard)?
12. Are condition data stored and tracked? If so, how?

Appendix C: Survey Call Log

District	Division	Name	Job Title/ Description	Date	Time
South Atlantic Division	N/A	Bob Fulton	Dam Safety Program Manager	11/27/07	10:00
Jacksonville	Engineering	Brent Trauger	Dam Safety Program Manager	11/28/07	9:50
Jacksonville	Operations	Donnie Kinard	Chief, Multi-Projects Funding; Project Manager	11/29/07	1:00
Rock Island	Operations	Steve Russell	Chief of Operations	12/3/07	2:02
Rock Island	Engineering	Kirk Sunderman	Project Engineer	12/5/07	8:30
Pittsburgh	Operations	Jim Fisher	Project Manager for Asset Management (temp)	12/5/07	2:00
Pittsburgh	Business Resources	Steve Fritz	Program Analyst	12/7/07	12:40
St. Paul	Operations	Leon Mucha	Program Manager	12/11/07	10:05
Rock Island	Engineering	Glenn Hotchkiss	Dam Safety Program Manager	12/14/07	8:30
Rock Island	Operations	Bill Gretten	Operations Manager	12/14/07	10:05
Southwestern Division	Business Technical	Tommy Schmidt	Dam Safety Program Coordinator/Manager	12/17/07	9:30
Great Lakes and Ohio River Division	Program Management	Bill Harder	Navigation Business Manager	12/18/07	9:15
Rock Island	Operations	Dennis Shannon	Chief, Locks and Dams Section	12/18/07	1:10
North Atlantic Division	Business Technical	Dan Rodriquez	Dam Safety Program Manager	12/20/07	12:05
Philadelphia	Engineering and Construction	Bruce Rogers	Dam Safety Program Manager / Levee Safety Program Manager	12/21/07	12:00
Rock Island	Engineering and Construction	Denny Lundberg	Chief, Engineering and Construction	1/2/08	9:00
Omaha	Engineering Risk and Reliability	Jeff McClenathan	Hydrologic Lead	1/7/08	10:30
Northwestern Division	Business Technical	Laila Berre	Dam Safety Program Manager	1/8/08	10:20
Mississippi Valley	Engineering	Dwayne Stagg	Dam Safety Program	1/8/08	3:00

District	Division	Name	Job Title/ Description	Date	Time
Division			Manager		
Mobile	Engineering	Davood Tashbin	Dam Safety Program Manager	1/10/08	1:00
Louisville	Engineering	Rick Schultz	Leader, Risk and Reliability Directory of Expertise (DX) for Mechanical	1/16/08	11:00
Louisville	Engineering	Tim O'Leary	Regional Technical Specialist (Geotech)	1/16/08	2:00
Portland	Operations	David Bardy	Assistant Operations Project Manager	1/18/08	1:00
Tulsa	Operations	Steve Chapman	Maintenance Manager for Operations	1/23/08	2:30
St. Paul	Engineering	Steve Sandquist	Periodic Inspection Team Leader	1/29/08	10:30
Sacramento	Engineering	Rick Britzman	Dam Safety Program Manager	2/4/08	10:45
Baltimore	Engineering	Jim Snyder	Dam Safety Program Manager	2/4/08	1:00
Baltimore	Operations	Joe Ignatius	Chief, Flood Protection and Natural Resources Section	2/6/08	9:35
Baltimore	Operations	George Bielen	Operations Manager for Susquehanna River Project	2/6/08	1:10
Portland	Engineering	Jim Hinds	Dam Safety Program Manager	2/7/08	8:30

Appendix D: Deficiency *vs.* Distress Discussion

Deficiency vs. Distress-Based Inspection and Asset Management Approaches: A Primer

Don Uzarski, Ph.D., P.E.

Investing in a capital asset management program for existing, multi-building portfolios can yield pay backs such as larger budgets, more efficient execution, improved buildings, satisfied tenants, and grateful owners. It can also help eliminate unforeseen demands on daily maintenance operations and replace chaos with order. Questions it answers for facility managers include: “What work do I need to do?” and “How much will the work cost?”

There are two distinctly different methodologies for answering these questions: a deficiency-based approach and a distress-based approach. From time to time confusion occurs regarding what a deficiency is and how it differs from a distress. Some people erroneously believe that they are one in the same. More importantly some may not fully grasp how the differences impact the capital asset management process. This primer is intended to provide the necessary clarity.

Deficiency-based Approach

This most common approach consists of an experienced inspector (or inspection team) going to a facility and recording “deficiencies” or problems that need to be fixed. Deficiency examples are, “Repair leaky roof” and “Paint conference room.” As part of the inspection process, the inspector will usually estimate the rough work quantity and later, usually in the office, also estimate a scoping cost estimate. Often inspectors will attempt to estimate a “remaining service life” for components. For example, an air handling unit may be old, but working. An inspector may feel that it needs to be replaced in 2-3 years and, thus, may record that as a deficiency.

Upon the completion of the facility inspection and follow-on office work, a list of deficiencies for that facility is compiled. These deficiencies form individual work item “candidates.” Some work items may be combined into

larger and logical project “candidates.” (Note: To avoid semantics issues, for the purposes of this discussion any work that is uniquely identified, regardless of scope and cost, is simply referred to as a “work item.”) All work items are candidates for funding and thus are added to the job jar containing other work items for other facilities and maybe for this facility, as well. The overall asset management process, which includes prioritizing the work items (in relation to one another) and budgeting to pay for them, then takes over until the work items are ultimately completed or cancelled. (Note: It is recognized that the scope of the work item may dictate the management process, fund source, priority, etc.)

The skill and experience of the inspector are crucial to the process because considerable judgment must be exercised. Other than when brand new, facilities are not expected to be, nor do they need to be, in pristine condition. Some degradation is expected and allowed. So, the inspector must exercise considerable judgment as to what is a recordable deficiency and what is not. This is a subjective call. In the inspector’s mind, some sort of a standard exists. However, two different inspectors may very well have differences in opinions. Even if an agency or organization attempts to establish standards, they are subjective, at best, and open to interpretation by inspectors.

Condition assessment metrics are a key element to facility asset management. These metrics, though, are dependent on the inspection approach. Deficiency-based condition assessment consists of summing the total costs of all of the deficiencies. This summation is sometimes divided by the replacement value of the facility to provide the commonly known “Facility Condition Index (FCI).” This FCI value (or derivatives such as the Federal Real Property Council’s CI = 1 – FCI) is used in the asset management process to whatever purpose is deemed useful by the agency or organization. Normally, the usage serves a strategic role in work planning and execution. Usually, though, condition assessment does not drive inspection planning or execution. Facilities (and their respective components) are most often scheduled for inspection based on the calendar, not on their condition. (There are exceptions, of course).

With a deficiency-based asset management approach, work item creation occurs at the beginning of the process. It is the creation and periodic refreshing of the job jar that drives the process. An unfortunate aspect of this is that the work items become out-of-date over time. A new inspection is needed to refresh. The degree of “staleness” will vary depending on the

degradation mechanism, degradation rate, and time since the last inspection (sometimes years). Further degradation affects the magnitude of the deficiency and repair scope. Consequently, asset management decision-making is often based on out-of-date information.

Distress-based approach

A distress-based approach consists of a trained inspector (or inspection team) going to a facility and recording what is wrong as defined by a finite and standardized "distress type" list. Examples include "cracked," "damaged," "broken," and "stained." Then for each distress type found, a "severity level" is assigned that addresses "how bad" the distress is. Usually, there is a choice of three, with "Low" implying minor, "High" implying life-safety and/or other critical attributes, and "Medium" implying serious, but not critical. Finally, the inspector records the density that quantifies the extent of the distress. All subcomponents for each component are inspected. Subcomponents that are "Defect Free" are also noted. Inspectors do not determine a repair scope or cost, nor do they attempt to estimate a "remaining service life" for components.

Upon the completion of the facility inspection, the complete list of distress types, severity levels and density for each component subcomponent is compiled. There is no attempt or need to identify individual work item "candidates" at this point. Rather, these distresses provide the data needed for determining the condition of the various building components. It is the condition assessment of the various components that will drive the work item generation process later in the overall asset management process. Then, once the work items are generated, the asset management process including prioritizing the work items and budgeting, continues until the work items are ultimately completed or cancelled. (Note: As it is in a deficiency-based approach, the scope of the work item may dictate the management process, fund source, priority, etc.) How the work items are actually generated is discussed below.

While inspector skill and experience is always a plus, those attributes are not crucial to a distress-based inspection process. This is because inspector judgment is minimized. What is crucial is that inspectors follow the standardized definitions of distress types and severity levels to ensure proper identification. They must also have the ability to accurately measure or estimate density and they must adhere to a structured inspection process. In other words, inspectors need to follow the "rules." By following the rules, different inspectors will identify the same distress types, severity

levels, and (within reasonable error) density. Condition standards do not enter into the inspection data collection process.

Distress-based condition assessment is more robust than deficiency-based condition assessment. Not only can a distress-based approach provide the same backlog, FCI, or FCI derivative metrics, but it also provides for a “Building Condition Index (BCI)” series of metrics. The BCI series is a condition measure on a 0-100 scale and is applicable to all levels of the building hierarchy (component-section, component, system, and building) and building groups. The lowest level is a component-section which is a component identified by material and type. For example, a wall component may consist of two component-sections: wood and masonry. This is needed because service life and degradation will vary based on material and type. These, in turn, affect work needs. The Component-Section Condition Index (CSCI) is computed from deduct values associated with distress types, severity levels, and density. Deduct values are points that are subtracted from a perfect score of 100. Component-sections are the “management units” upon which work decisions are made. Their condition (as measured by the CSCI) will establish work item scope and cost. The other hierarchy CIs (roll-up values from the CSCI) serves other asset management purposes. CSCIs (and the other CIs) can also be historically tracked and predicted. Rates of deterioration can be computed and remaining service life can be estimated.

The CSCI serves many strategic and tactical purposes related to work planning. One strategic purpose is that minimum desired condition standards can be set based on them. Tactically, if the condition is above the standard, no work item is needed or generated. If the condition is below, a work item is needed to raise the condition to a value above the standard. Thus, work items are not generated by a subjective interpretation by inspectors, but rather in an objective manner based on agency or organization goals and needs. Another use takes advantage of the relationship that work item cost is related to the CSCI. Thus, a work item scoping cost estimate can be computed by simply knowing the CSCI. Repair versus replace decisions will be based on economics, standards, and the computed remaining service life. Inspectors do not spend time back in the office after the inspection computing costs.

With a distress-based asset management approach, work item creation occurs towards the end of the process. Work item generation is a result of the process described above, not the prime input to the process. Since the

CSCI can be predicted from its last known point (the last inspection) to the present and future, work items are automatically updated based on the predicted CSCIs. Thus, current and future work needs and estimated costs do not become stale. As a result, asset management decisionmaking is based on “real-time” information. Also, the CSCI can drive the inspection planning and execution process. The various component-sections in a facility can be scheduled for inspection based their expected condition (and other variables, including deterioration rates), not the calendar. New inspections serve to confirm or adjust CSCIs and refine the degradation (life-cycle) curves for the various component-sections.

Is One Approach Better than the Other?

Since both approaches answer the questions, “What work do I need to do?” and “How much will the work cost?” does it matter which approach is used? Is one better than the other? The answer is, “It depends ....”

Deficiency-based decisions are prevalent in our everyday lives. It is the approach used when we take our autos in for routine service and check-up, call the heating and cooling company to perform routine service and inspect our home heating system, have a home inspection, and simply see things (deficiencies) in our homes that need repair and decide to fix them or not. Thus, it is an approach with which we are all familiar and comfortable. It works well in the examples cited because it is simple, there is an inherent knowledge of the asset, the asset portfolio size is small, and there is a comfort factor associated with the consequences of the decision (do the work; do not do the work).

However, when asset management encompasses more than just a few facilities, a distress-based approach is most advantageous. The differences in the approaches were described above, and it is those differences that highlight the advantage of a distress-based approach. With all but the smallest of facility portfolios, the inherent knowledge of any individual asset is diminished (and in many cases minimal) and decisionmakers must rely on information from others. This information needs to be objective, consistent, and current. Plus, it must be economical to gather. In short, a distress-based approach is robust, faster, consistent, and less expensive when compared to a deficiency-based approach, especially when the efficiencies of modern computer applications are employed.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The U.S. Army Corps of Engineers (USACE), Directorate of Civil Works is in the early stages of implementing infrastructure asset management principles to better manage its civil works infrastructure. This effort is being done, in part, in response to Executive Order 13327, which mandates a pragmatic and consistent approach to Federal agency management of real property.An understanding of how current inspection and condition assessment efforts support infrastructure asset management is needed if USACE is to move forward. The U.S. Army Research and Development Center, Construction Engineering Research Laboratory was tasked with surveying a number of USACE District and Division personnel about their inspection and condition assessment practices and how that supports decisions related to infrastructure asset management.

This report: (1) describes the demographics of the survey participants and explains the different approaches to condition assessment in use within USACE. (All rely on a deficiency-based approach, i.e., deviations from standards or from known benchmarks, to inspection.); (2) describes how inspection and condition information is used in developing work packages, budgeting, and prioritizing work, and also how inspection and condition information is reported for management; (3) provides recommendations for future opportunities that, if developed and adopted, would strengthen the process.

15. SUBJECT TERMS
civil works, condition assessment, asset management, infrastructure

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